DEVELOPMENT OF COST ESTIMATING TECHNIQUES AND RELATIONSHIPS FOR UNMANNED SPACE EXPLORATION MISSIONS

PRC R-870

October 28, 1966

Prepared for

California Institute of Technology
Jet Propulsion Laboratory
4800 Oak Grove Drive

Under JPL Contract 951468

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Prepared by

F. E. Hoffman
G. W. S. Johnson
L. H. Simonsen

PLANNING RESEARCH CORPORATION
LOS ANGELES, CALIF. WASHINGTON, D.C.

Planning Research Corporation
Contract 951468

R-870

MAN 1968

ERRATA

Page 14	Change 7 to 9 Add footnote as follows: 9 is Spacecraft total program cost = TPC minus launch vehicle cost minus mission support and SFO costs as shown on pages 28 and 42.
Page 19	Under Section 5a, Nominal STPC, delete the second sentence reading: "The nominal program cost......" Add the following after the last sentence: The nominal STPC, defined as the sum of 9 and the subtotal of Mission Support and Space Flight Operations cost shown on page 42, amounted to $874.4 million.
Pages 28 and 42	Change the title to read: Program Cost Summary Change M. O. Equipment to read: M. O. Training Add the following footnote: To obtain 8, the increment in systems integration cost, enter CER 12A with cost 7 and obtain the increment in cost between one spacecraft module and the applicable number of spacecraft modules.
Page 40	Under Electrical Power place an asterisk after Fuel Cell* Add footnote below: *Whereas batteries may be a better engineering choice, fuel cells are shown to illustrate the method.
Page 42	Add $419.75 in 7 blank Change sterilization cost from $80.20 million to $77.40 million and change the total to $1,040.43 million
Page 45	Under Utilization of Cost Categories change "Fabricate and Assemble Flight Hardware" to Fabricate, Assemble and Test Flight Hardware Add footnote ** below: Design/Development is defined as Design, Fabricate and Assemble Test Hardware, and Ground Development Testing.

102

Appendix

Exhibit 2B	Change cost (dollars per pound) to cost (dollars per pound of thrust)
Exhibit 3B	Change First Unit Cost - Dollars/Pound of Thrust, 10^3 to First Unit Cost - Dollars/Pound of Unit Weight
Exhibit 8.6A	Change Dollars per Watt/Hour and Output in Watt/Hours to Dollars per Watt - Hour and Output in Watt - Hours
	Delete learning curve = 100 %
	Change Design and Development cost = 0 to Design and Development cost = 100 x First Unit Cost
	Under Batteries, delete second and third sentences
	Under Mission Sensors, change IR spectometer to IR spectrometer

PROGRAM COST SUMMARY

ITEM	① DESIGN/DEVELOPMENT	② COST OF TEST ARTICLES	③ D/D PLUS TEST ARTICLES	④ INTEGRATION	⑤ COST OF FLIGHT ARTICLES	⑥ TOTAL COST
			① + ②	③ & CER 12A		③ + ④ + ⑤
Spacecraft Module 1						
2						
3						
—						
—						
S/C Systems Integration - Increment Ref: ⑦ & CER 12A		Σ ⑦			Σ	
					⑧	
				S/C TPC	→ ⑨	

MISSION SUPPORT AND SPACE FLT OPNS	DESCRIPTION / INPUT	REF CER	OPERATION	COST
Program Management		—	0.05 ⑨	
SETD	Mgt Mode/Tech M/P Ratio	15A	K_1 ⑨	
Phase A	Adv Studies	—	0.01 ⑨	
Phase B	Conceptual Design	—	0.01 ⑨	
Phase C	Project Definition, System Design, & Critical Hdw. Dev.	—	0.05 ⑨	
Adv. Development	N_R = = Number of High Risk Sub-Systems	—	0.05 ⑨ $(1+\sqrt{N_R})$	
Sterilization	F = ; W_c/W_s = ; N =	13	/100 ⑨ x N/4	
M.P. Equipment	Mission Peculiar Equipment At SFOF & DSN	14	Σ =	
M.O. Training	Mission Operations Training; T =	—	$0.60 \times 10^6 \times (T+3) + 0.2$(MPSC)	
Space Flt Opns	Mission Time (T) Months ; T =	—	$0.20 \times 10^6 (T+3)$	
Post Flt Analysis	Mission Time (T) Months ; T =	—	$0.40 \times 10^6 (T+3)$	
Mgt Impltn Mode	Mgt Implementation Mode:	15	K_2 ⑨	
Schedule / Program Chg		16	/100 ⑨	
Launch Vehicle				

1965 DOLLARS

TABLE OF CONTENTS

I. INTRODUCTION/SUMMARY

This document is the final report submitted under JPL Contract No. 951468. The study performed under this contract can best be described by listing the major tasks:

1. Develop a cost estimating technique for unmanned space exploration missions based on applicable methodology and pertinent data from the Space Planners Guide, United States Air Force, Air Force Systems Command, 1 July 1965.
2. Describe the cost categories and estimating relationships developed and their relationship to the various phases of a space project.
3. Provide a preliminary cost model based on initial efforts.
4. Demonstrate the use of the estimating technique by application to two mission examples--one past mission, Mariner IV, and one future mission, a combined Mars orbiting and landing mission.
5. Perform a sensitivity analysis to determine the importance of various cost categories and parameters in predicting project costs:
   a. The cost categories shall include, but not necessarily be limited to, such items as design, development/operations, and various subsystems.
   b. The parameters shall include, but not necessarily be limited to, such items as periodic launch schedule and program changes.
6. Refine the previously developed cost estimating technique as indicated by the sensitivity analysis.
7. Demonstrate the application of the refined cost estimating technique by repeating the mission cost examples prepared under item 4 above.
8. Prepare a final report showing:
   a. A clear definition and description of all costing categories, relationships, and techniques developed.

b. Documentation to substantiate engineering judgments and identify data sources.

c. Results of the mission cost applications.

d. A discussion of the scope and accuracy of the cost estimating techniques developed.

This final report has been prepared to satisfy two different demands. One part of this report is devoted to describing the development of the cost model and to discussing the scope and accuracy of the techniques and relationships. Other parts of this report are directed toward space system costers; consequently, blank standardized forms are provided in the Appendix to assist the user in obtaining rapid results for launch vehicle procurement costs and unmanned spacecraft design, development, fabrication, ground testing, and space flight operations costs.

II. TECHNICAL DISCUSSION

A. General Approach and Data Sources

In developing a cost model for unmanned space exploration missions, the quantity, quality, and the cost categories used in the available data must be considered. There is no immediate advantage in developing a cost model based on an elaborate framework of cost categories not used in the past, since this approach can only lead to a maximum of judgments and possible errors in distributing costs to new categories.

The cost model shown in this report is based on minimizing the number of engineering judgments required to distribute costs to the categories chosen. The principal data sources are shown in Table 1. An inspection of this table shows that the data sources for this report are a combination of past studies, Planning Research Corporation's Data Bank, recent industrial contacts with nine major launch vehicle and spacecraft contractors, and an analysis of NASA and JPL cost data on five past spacecraft systems.

B. Cost Categories and Relationships

Initially in this study effort, the cost categories that appeared significant were: launch vehicles, spacecraft, and support systems. These categories were later expanded to include:

- Design
- Manufacture hardware (or purchase)
- Facilities (build or inherit)
- Ground development testing
- Space flight operations

These categories were then to be supported by appropriate detailed cost-estimating relationships (CER's). Later in the study it became apparent that insufficient data were available to separate design and ground development testing into distinct cost categories, and launch vehicle development, as well as facilities, were recognized to be beyond the scope of this study.

TABLE 1 - DATA SOURCES

1. Launch Vehcile Components Cost Study
   Lockheed Missiles and Space Company, Technical Report, Volume II, LMSC-895429, June 30, 1965

2. Launch Vehicle Systems Cost Model
   Lockheed California Company, Technical Report, LR 17825, June 15, 1964

3. Spacecraft Cost Data Bank - Planning Research Corporation

4. Space Planners Guide -
   USAF, AF Systems Command, July 1, 1965

5. Synopsis of GSFC Accomplishments on Development of Cost Estimating Relationships........ for Unmanned Satellite Programs
   W.A. Mecca, Jr., Goddard Space Flight Center, March 1966

6. Results of Industrial Contacts with Nine Major Launch Vehicle and Spacecraft Contractors
   PRC Data File

7. Analysis of NASA and JPL Cost Data on Ranger, Lunar Orbiter, Syncom, Surveyor, Orbiting Astronomical Observatory Spacecraft - PRC Data File

This realization posed no particular problem since launch vehicles are usually inherited development, and facilities are either inherited from other programs or are carried in budgets separate from a particular spacecraft system.

In view of these considerations, the following general framework for the hand cost model was adopted:

1. Launch Vehicle (Procurement)

   Subsystems ---------------------------------CER's

   Activities such as: -------------------------CER's

   - Transportation
   - Launch Services
   - Acceptance Testing

   Design/Development and First Unit Costs

2. Spacecraft (Design/Development and Fabrication)

   Subsystems ---------------------------------CER's

   Activities such as:

   - Systems Integration

   Design/Development and First Unit Costs

3. Mission Support and Space Flight Operation

   Program Management

   Systems Engineering and Technical Direction (SETD)

   Sterilization of Entry Capsule

   Mission Peculiar Equipment at Space Flight Operations Facility (SFOF) and Tracking Sites

   DSN (Inherited)

   Space Flight Operations

   Post Flight Analysis

   Management Implementation Modes:

   - Laboratory Management
   - Systems Management

   Advanced Development

   Phases A, B, and C

   Schedule/Program Changes

C. Preliminary Cost Model

A preliminary cost model was prepared early in the study.[1] This approach not only provided an early output for spacecraft systems costing, but also served to emphasize the problem areas in developing an unmanned spacecraft cost model.

One difficulty that immediately became apparent was the defining of subsystems and distribution of the weights to appropriate cost categories. This problem arises since different scientific and engineering organizations use different names for subsystem hardware development tasks. A simple, standardized weight distribution form solved this problem and serves to display any judgments required. An example is shown in Table IA.

Other problems were apparent in the preliminary cost model and were overcome largely by further definition of the subsystems or by addition, deletion, splitting, or combining subsystem categories. Costs for transportation, acceptance testing, and propellants were retained for launch vehicle but dropped for spacecraft because of their minuscule effect.

D. Final Cost Model

The final cost model is now presented. The individual items are described in the following subsections: launch vehicle, spacecraft, mission support, space flight operations, and management implementation modes and management alternatives in schedule/program changes.

Subsection E contains a demonstration of the final cost model using one past and one future space mission. The detailed CER's are shown in this section.

1. Launch Vehicle

The launch vehicle cost model is a building block approach for estimating the cost of any combination of stages, engines, and either LOX/RP-1 or LOX/H_2 fuel.

---

[1] Development of Cost Estimating Techniques and Relationships for Unmanned Space Exploration Missions, Planning Research Corporation, Report D-1206, April 29, 1966.

The launch vehicles used in planetary exploration have been systems that were operational--having been developed for other programs. However, they were easily adaptable to planetary flights. Future planetary programs are expected to also use launch vehicles that are available rather than developing special launch vehicles for this specific program. Consequently, the launch vehicle cost model is based on procurement costs of vehicle stages and engines that are in production. Large solid rockets are not considered.

The cost elements for each stage are identified separately in the model. Thus, in any stage, the three hardware items, structure, propulsion, and guidance and control, are costed first, followed by transportation, acceptance tests, launch services, and propellants. Two of these elements, guidance and control and launch services, are not costs which are applicable to each stage separately; they are a single cost for each entire launch vehicle. However, the guidance and control is usually in the top stage, and in the subsequent demonstration, it has been included as a part of the top stage. To simplify the cost model, the launch services were also included in the upper stage.

A choice of learning curves is also provided since the learning for various hardware items varies significantly. After selecting an appropriate learning curve and the production quantity, a learning factor is obtained from Exhibit LV-8. This learning factor, times the first unit cost, provides the cost of the item under consideration. If more than one of the items is used per stage, then it is necessary to make one more calculation, as shown in Table IIA. For planning purposes, the following learning curves may be used:

Launch vehicle stages	90 percent learning curve
Liquid engines	90 percent learning curve
Guidance and control	90 percent learning curve

Cost estimating relationships (CER's) were developed for each of the elements appearing in the launch vehicle model. The Space Planners Guide[1] was used as a departure point since it provided reasonable initial answers.

---

[1] The Space Planners Guide, USAF Report dated 1 July 1965.

However, this information was updated with recent data from manufacturers and various NASA reports. Discussions with many NASA officials also provided information and an insight into judging the accuracy of the reported data.

In some cases an entirely new CER was developed rather than using the parameters depicted in past studies. This approach was used when the new parameters appeared to provide a more easily understood relationship. The CER for structures, Exhibit LV-1, is an example where pounds of propellant was previously used as the quantifying parameter and cost in dollars as the resultant. It is believed that dollars-per-pound of structure provides a more meaningful comparison of one stage structure with another than total cost in millions of dollars.

2. Spacecraft

Spacecraft costs have been categorized largely by the subsystems such as structure, propulsion, navigation and guidance, stabilization and control, communication, and others. In addition, the costs are further categorized into Design/Development and first unit costs for hardware fabrication of test and flight articles. In this report, the cost of test and flight hardware is assumed to be at first unit cost under ten spacecraft. For greater numbers of spacecraft the learning curve factors can be used.

The cost of aerospace ground equipment (AGE), tooling, and special test equipment are applied against Design/Development support only. In a production program involving ten or more identical spacecraft, additional AGE, tooling and test equipment would be required.

Systems integration costs as shown in Table III are required for subsystem integration and one interface. For multiple module spacecraft the incremental cost of integration between modules is shown on the summary sheet in Table IV and Exhibit 12A.

Environmental control systems costs (ECS) are usually large in manned spacecraft; however, in the unmanned spacecraft analyzed, the

ECS was largely thermal control and in most cases louvres or simple structure. In view of this recurring situation ECS was deleted as a cost category and the items were usually costed as structure.

Entry Capsule Sterilization

Sterilization of planetary spacecraft is expected to cause a major change in assembly and test techniques. Clean rooms and remote handling procedures are anticipated as minimum requirements. This will result in a large increase in man-hours for assembly and test.

This increase is expected to be applicable only to that portion of the spacecraft that must be sterilized. The actual increase in program cost is expected to be a direct function of the present man-hour requirement for assembly and test.

The following formula has been developed to determine the percentage increase in total spacecraft program cost when a portion or all of the spacecraft is assembled and tested under sterilized conditions.

$$S = \frac{1}{4} k \frac{W_c}{W_s} (f-1)(100) \frac{N}{4}$$

where

- S = percentage increase in total spacecraft program cost due to sterilization
- k = fraction of total spacecraft program cost for personnel, i.e., (k + material fraction and subcontract fraction) = 1
- W_c = weight sterilized
- W_s = total weight of spacecraft less expendables
- f = factor by which man-hours must be increased to perform sterilization
- N = number flight articles sterilized

The constant 1/4 is the ratio of the assembly and test cost without sterilization, to the total spacecraft personnel cost, i.e., assembly and test account for approximately 25 percent of the total spacecraft personnel cost.

The constant 4 is the average number of flight articles in the programs from which this formula was derived.

Inspection of two past programs shows that k = 0.40 , and Exhibit 13, based on the above relationship, shows the sensitivity of total spacecraft program cost to the factor by which assembly and test man-hours must be increased due to sterilization. The exhibit also provides this sensitivity for various ratios of the sterilized portion to the total spacecraft weight.

For example, if the weight of the capsule on the Mars Advanced Orbiter/Limited Lander that requires sterilization is 0.25 of the total spacecraft weight, and if a man-hour factor of 5 is selected as the expected increase for sterilization, then the spacecraft program cost will be increased by 10 percent. A manpower amplification factor of 5.0 is recommended until current research in this area is completed.

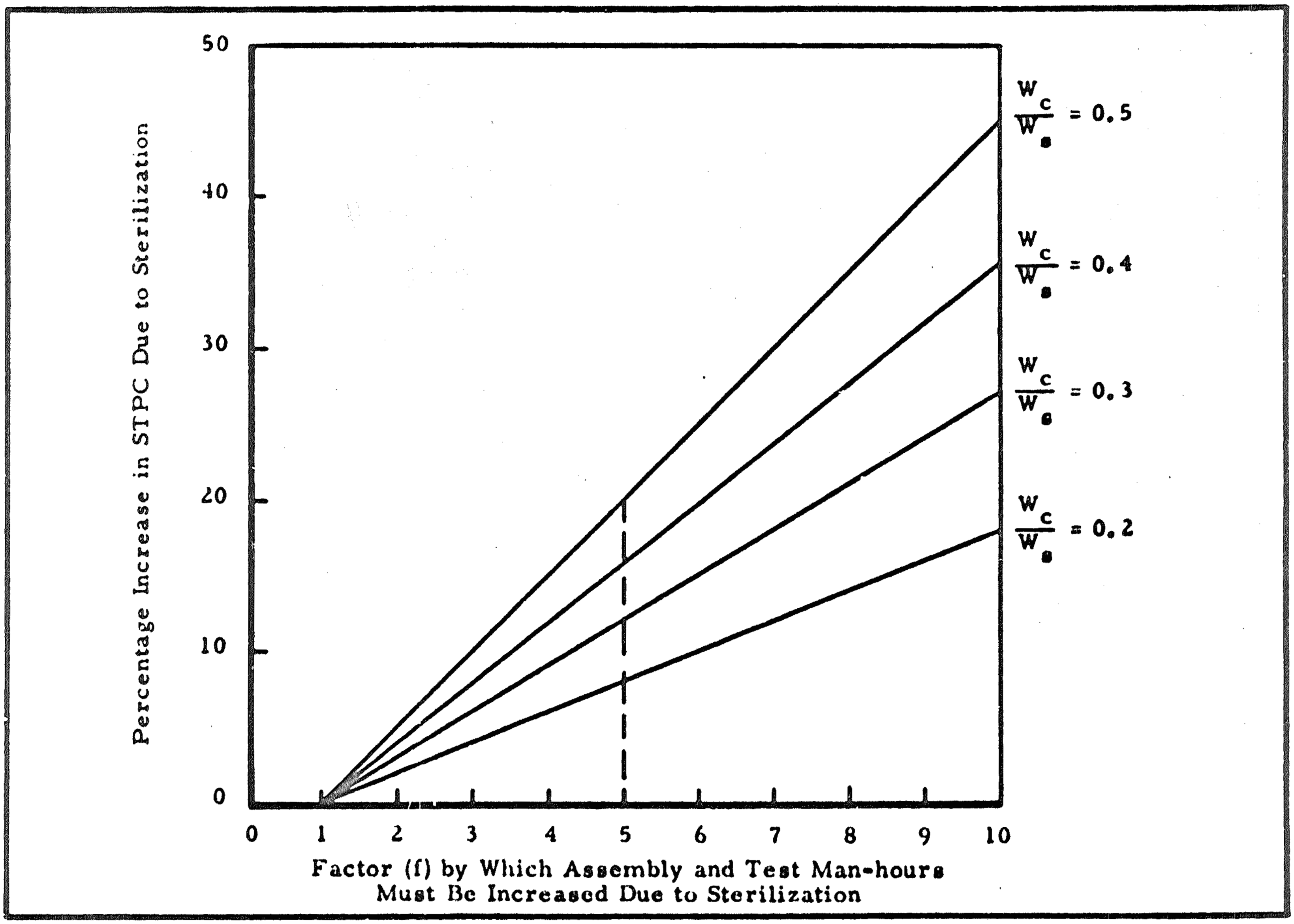


EXHIBIT 13 - INCREASE IN THE SPACECRAFT TPC DUE TO STERILIZATION

RE-ORDER No. 66-664

3. Mission Support and Space Flight Operations

Whereas previous sections of this report were concerned with launch vehicle procurement and spacecraft design/development and fabrication costs, this section is devoted to costs for mission support and space flight operations.

The cost categories considered here are the following:

- Program Management
- Systems Engineering and Technical Direction (SETD)
- Phases A, B, and C
- Advance Development
- Entry Capsule Sterilization
- Facilities (General)
- Mission Peculiar Equipment (MPE)
- Mission Operations Training (MOT)
- Space Flight Operations
- Post Flight Analysis

The cost for program management is largely attributable to salaries and administrative support for the spacecraft system program office; whereas the cost of systems engineering and technical direction (SETD) is attributable to salaries, administrative support, and studies to provide initial systems engineering and technical advice to the Spacecraft System Program Office.

Phases A, B, and C costs refer to system procurement phases:

- Phase A--Advanced Studies.
- Phase B--Conceptual Design.
- Phase C--Project Definition, System Design, and Critical Hardware Development.

Advance Development costs refer to starting development of long lead time items, initiating additional research and development in new or unestablished technologies, such as sterilization procedures or entry capsule heat shield materials.

Sterilization costs refer to the increase in total spacecraft program cost due to increased assembly and test manpower to sterilize the entry capsule. Increases in the cost of facilities required by sterilization procedures are not considered.

Sterilization costs are shown in Section D.(2) and CER 13.

Since general facilities such as tracking sites for the Deep Space Net (DSN) are usually carried in other budgets or are at least not chargeable to a particular program, only mission peculiar equipment located at Space Flight Operations Facility (SFOF) and DSN has been considered. A CER for this equipment is shown in Exhibit 14.

Mission Operations Training costs refer to the training of personnel for mission operations in SFOF including the necessary software. Space flight operations costs as shown are solely cognizant scientific and engineering personnel on duty at SFOF to ensure adequate and timely command decisions regarding the spacecraft and mission sensors (or experiments) during flight operations. Similarly, post flight analysis cost is attributable to scientific and engineering personnel for a time span.

Tables IV, IVA, X, and XA illustrate the mission support and spaceflight operations costs as well as the associated time phasing.

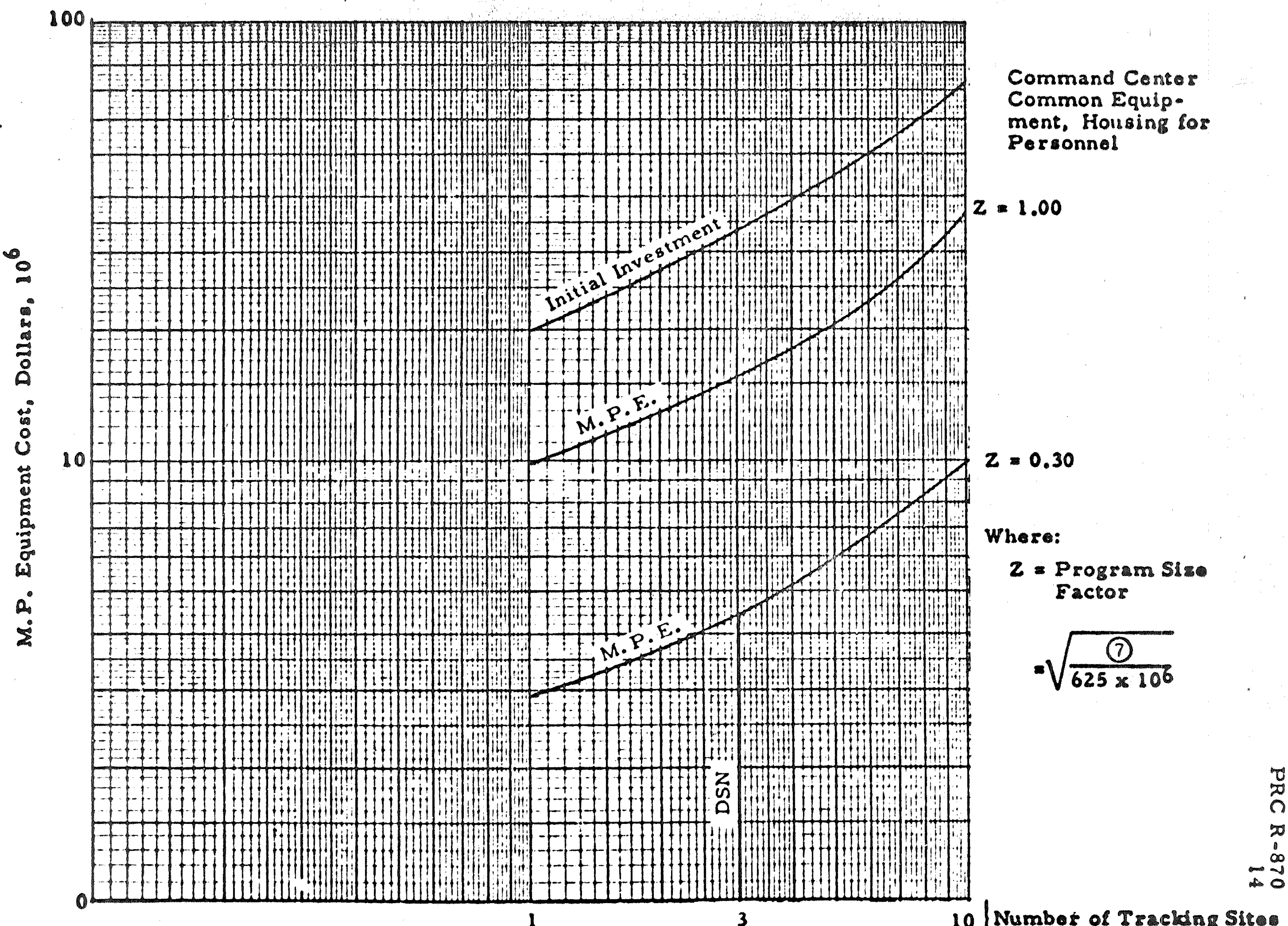


EXHIBIT 14 - MISSION PECULIAR EQUIPMENT (MPE) COST AT SFOF AND DSN

4. Management Implementation Modes

The impact of management implementation modes on spacecraft costing can be considered by examining the two broad choices available:

a. An in-house laboratory development where only materials and a few subsystems are purchased and all final assembly and development testing is in-house. The Ranger Block III represents an example of this laboratory management mode.

b. A prime systems contractor is assigned responsibility for overall spacecraft design, fabrication, and development testing. The Spacecraft Systems Program Office would then perform the functions of technical and administrative direction. The Surveyor project is an example of this systems management mode.

In general, an in-house laboratory mode is most desirable when the root technology is not fully developed and small quantities of spacecraft and numbers of flights are involved. This mode is also more compatible with small spacecraft (1,000 pounds dry weight). In contrast to laboratory development, systems management is usually considered when the project is large in resources required and the root technology is well established or easily extended in a small advanced development phase carried along as concurrent development.

In order to quantify and compare these two management implementation modes, Exhibit 15 has been prepared, in which the nominal total spacecraft program cost is based on an in-house laboratory development. The nominal total program cost is based on the following premises:

a. Laboratory management and development

b. Professional manpower cost ($30,000 per year)

c. Nonprofessional manpower cost ($20,000 per year)

d. The professional manpower consists of 45 percent of the total project manpower. This is an average for the entire project since the earlier study phases usually have a higher percentage.

e. Only 40 percent of the entire program cost is attributable to personnel cost. The balance is used to purchase material and subsystems.

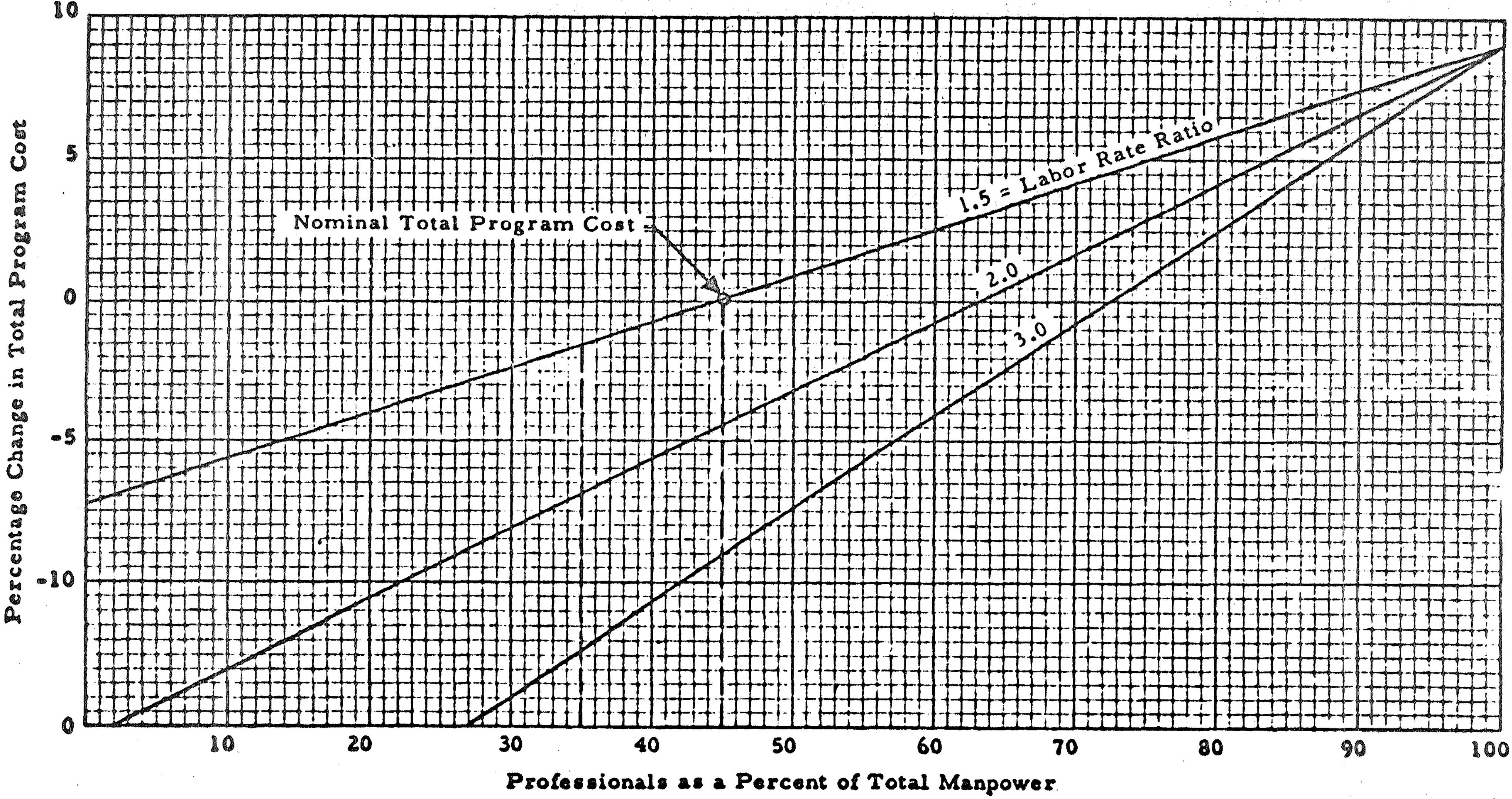


EXHIBIT 15 - MANAGEMENT IMPLEMENTATION MODE

From Exhibit 15, it can be seen that the cost of the first mode, laboratory management, can be adjusted by changing the percentage of professionals assigned to the project. In this case, the effect on the total project cost can be determined by proceeding along the line passing through the nominal-total-program cost. If the percentage of professionals were to be held at 45, but the nonprofessionals were to be paid only $15,000 per year instead of $20,000, then the effect on the total program cost would be determined by proceeding vertically downward through the nominal-total-program cost. The result would be a saving of 4.5 percent.

If the second mode, systems management, were chosen, it is only necessary to know the professional manpower as a percentage of the total, and the annual average personnel labor rate for professional and nonprofessional manpower. Exhibit 15 is based on an annual labor rate of $30,000 for professionals. If this figure were to vary by more than $5,000, a new exhibit should be prepared.

In the foregoing comparison of the two basic management modes, it was assumed that the same tooling and special test equipment investment would be required in a laboratory development or a systems management program.

An inspection of Exhibit 15 shows that under systems management, a percentage decrease of 7 percent in total spacecraft program cost can be realized if the professional manpower is 35 percent (a common ratio in the aerospace industry) of the total manpower, and the annual labor rates are $30,000 and $15,000 for professionals and nonprofessionals, respectively. Obviously these gains can be overshadowed by inefficiency in program control and unexpected difficulties in technical development requiring additional advanced development costs.

The 7-percent decrease in total spacecraft program cost shown in the foregoing example is partially offset by an increase in SETD expense in-house. This expense is a function of the number of personnel assigned to this activity. Exhibit 15A is a plot whereby the cost of this management activity is shown as a function of the ratio of the number of technical in-house personnel to the number of technical personnel assigned to the project by the systems subcontractor.

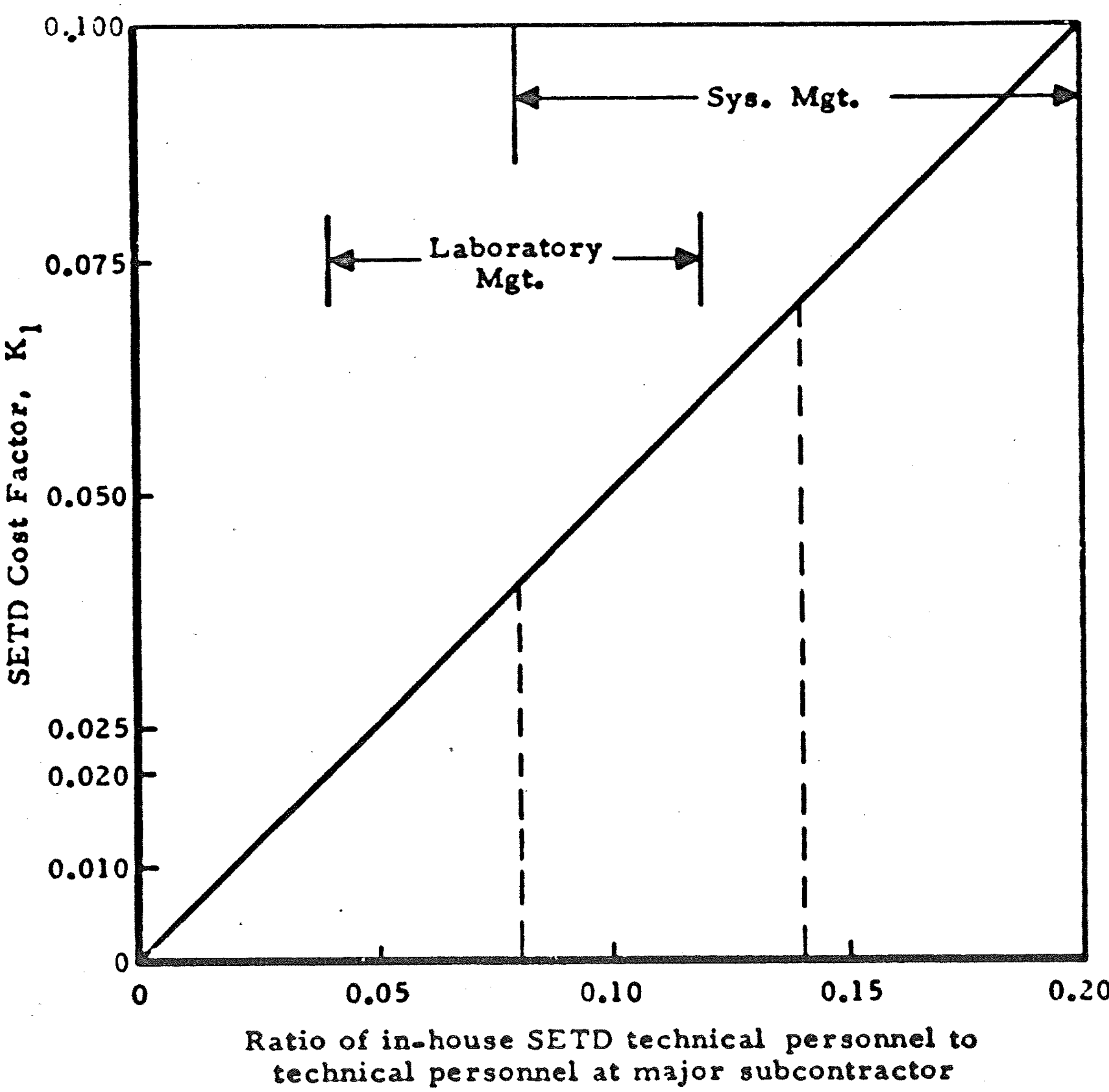


EXHIBIT 15A - SETD COST

5. Schedule/Program Changes

This subsection presents the variations in spacecraft total program cost (STPC) for various program management alternatives, the effect on STPC for parallel development in high risk areas, and a rescheduling of the launch and accelerated development in the high risk areas. The nominal STPC for the Mars Advanced Orbiter/Limited Lander mission was used as the baseline estimate to derive the effect of the program management alternatives on STPC.

a. Nominal STPC

For the Mars advanced mission, the design and development phase was four years; however, the results herein can be applied to other Phase D schedules. The nominal program cost as described previously amounted to $874.4 million. By an analysis similar to that presented in PRC Report D-1302, increases in STPC were developed for the modified cases as described below.

b. Parallel Development

Due to the launch date constraint and a 24-month mandatory delay, a form of insurance is available by having parallel development in selective high risk areas. No attempt was made in this study to quantify risk, but rather, based on engineering judgment, high risk items were chosen to be developed in parallel. The cost of the high risk items was doubled to account for development of alternative designs.

The spacecraft high risk items chosen were the guidance and control and the electrical power (RTG) subsystems. An alternate entry capsule was chosen to be developed in parallel. Only one capsule would be sterilized. An alternate throttleable engine design was chosen for parallel development for the propulsion module. The spacecraft support costs were increased by the ratio of the nonspacecraft support parallel development cost to the nonspacecraft support nominal cost case. The parallel development STPC was $960.8 million.

c. Periodic Launch Rescheduled

The nominal case with reschedule or postponement of the launch at some point was now examined. The worst point to reschedule will in general be at that point where the total spending rate is the highest. With any percentage cutback the rate of spending to maintain the remaining manpower and material will be a maximum. We have chosen the midpoint of Phase D as the reschedule decision point (worst case). The highest program cost with a reschedule of the launch date will occur with no cutback of manpower and material. A minimum expected cost would probably be something like a cutback of 2/3 with a linear buildup to the nominal rate a year before launch. One can foresee little variation in the cost for the last year before launch. The maximum cost with reschedule results in a cost of $1,151 million, while the minimum cost is $972.3 million, compared to a nominal cost of $874.4 million.

d. Accelerated Development

A third case was studied, where initially, the nominal program is chosen, and at a particular time (due to unforeseen difficulties) the program spending is accelerated in the high risk areas in order to meet the launch date. The high risk areas chosen were identical to the parallel development case. In the case presenting the high risk area, spending was tripled at the beginning of the second year of Phase D. Both the time for accelerated development and the increase in cost were somewhat arbitrarily chosen; however, it lends insight into the magnification of the STPC when rapid development is required. The accelerated costs also include increased space vehicle support costs. The total accelerated cost was $1,050 million.

Thus, a CER for program management alternatives, with regard to major schedule/program changes, has been developed. The results are presented in Exhibit 16.

EXHIBIT 16 - PROGRAM MANAGEMENT ALTERNATIVES

Schedule/Program Changes	% Increase in STPC
1. Nominal Program	0
2. Parallel Development (of alternate designs in high risks sub-systems from the start of Phase D)	22.0
3. Accelerated Development (crash development of three designs in each high risk sub-system from the quarter-point of Phase D)	37.5
4. Periodic Launch Rescheduled (to next launch opportunity at the mid-point of Phase D)	
A. no cut-back in level of effort	55.0
B. a two-thirds funding cut-back with gradual build-up reaching nominal spending levels one year prior to launch	24.0

23

E. Demonstration of the Cost Model

Two examples are used to demonstrate the cost model. The space missions chosen are Mariner IV, an unmanned Mars fly-by in 1964 and an unmanned Mars Advanced Orbiter/Limited Lander in 1973-1975. The description of the future mission and associated spacecraft was obtained from Jet Propulsion Laboratory personnel and is used only to illustrate a typical multi-module spacecraft. No preference to this design candidate is implied or denied by its inclusion here.

1. Mariner IV--Mars Fly-By in 1964

Distribution of Mariner IV Weights to Cost Categories

In order to display the weight distribution of the Mariner IV spacecraft to the appropriate cost categories, Table 1A has been prepared. In general the method of distribution is obvious; however, some remarks will be made to further clarify the table shown.

Structure

The principal items here are the primary octagonal structure, solar panels less the solar cells, six electronic assembly chassis, science platform structure, actuators, covers, superstructure, thermal control louvres and shields.

Electrical Power

The electrical power system is a paddle mounted solar cell system and the principal weight items are solar cells, battery, conversion and regulation electronics.

Stabilization and Control

The subsystem is primarily a cold gas attitude control system and the principal weight items are electronics, attitude sensors, nitrogen gas, solar pressure-vane control assemblies, and two attitude-control gas assemblies.

Navigation and Guidance

The guidance system is a radio command system supplemented by the attitude control system and sensors discussed above. The principal weight items are command electronics, central computer and sequencer (CC&S) and other electronics.

Communications

Under communications the principal weight items are RF transmitter and receiver and antennas.

Throughout Table IA the weight of the cabling has been distributed to the using subsystems.

TABLE IA - DISTRIBUTION OF MARINER IV WEIGHTS TO COST CATEGORIES

JPL Weights \ Cost Category	Experiments or Mission Sensors	Navigation and Guidance	Communications	Data Management	Stabilization and Control	Structure	Electrical Power	Propulsion
Structure (78.44)						78.44		
Antenna (7.43)			7.43					
Radio (34.40)			34.40					
Command (10.12)		10.12						
Power (70.95)							70.95 lbs. (0.34 KW)	
Solar Panels (79.02)						44.62	34.40	
CC&S (11.38)		11.38						
Data Encoder (22.43)				22.43				
Data Storage (16.89)				16.89				
Guidance and Control (63.29)		18.86			45.43			
Actuators and Pyrotechnics (12.21)						12.21		
Cabling (45.69)	7.62	7.62	7.62	7.62	7.62	7.62		
Propulsion (45.55)						3.80		43.75 (T = 50 lbs.)
Thermal Control (15.53)						15.53		
Science (59.41)	59.41							
Total (574.74)	67.03	47.98	49.45	46.94	53.05	162.22		

TABLE IIA

LAUNCH VEHICLE COST

Atlas D STAGE	QUANTIFYING PARAMETER	PARAMETER INPUT	REF. CER	FIRST UNIT COST (DOLLARS/LBS)	STRUCTURE (WT IN LBS)	FIRST UNIT COST (DOLLARS)	LEARNING CURVE	ITEM COSTED	REF CER	LEARNING FACTOR	COST OF ITEM (DOLLARS)	NUMBER ITEMS	COST (DOLLARS)
Structure	Stage Propellant Wt. (lbs)	247,500	Ex LV-1	620	24,200	15,000,000	90%	200	Ex. LV-8	0.445	6,700,000	1	6,700,000
Propulsion	Engine Thrust (lbs)	154,500/60,000	Ex LV-2	—	—	490,000/ 280,000	90%	450/250	Ex. LV-8	0.40[illegible]/0.420	196,000/ 118,000	2/1	510,000
Guidance and Control	Weight (lbs)	Not applicable to this stage	Ex. LV-3		—				Ex LV-8				
Transportation Air ☐ Ship or Rail ☐	Stage Dry Weight (lbs)	27,500	Ex. LV-4	—	—	—	—	—	—	—	—	—	3,400
Acceptance Test	Stage Gross Weight (lbs)	275,000	Ex. LV-5	—	—	—	—	—	—	—	—	—	210,000
Launch Services	L.V. Gross Weight (lbs)	376,000	Ex. LV-6	—	—	—	—	—	—	—	—	—	Not applicable to this stage
Propellants	Propellant Type	LOX-RP-1	Ex. LV-7	—	—	—	—	—	—	—	0.025/lb	247,500	6,170
												TOTAL	7,429,570

Other Pertinent Data

Engine Type [Liquid]

Engine Dry Weight (ea) (lbs) [--]

Stage Thrust (lbs) [369,000]

TABLE IIB

LAUNCH VEHICLE COST

Agena D STAGE 2	QUANTIFYING PARAMETER	PARAMETER INPUT	REF. CER	FIRST UNIT COST (DOLLARS/LBS)	STRUCTURE (WT IN LBS)	FIRST UNIT COST (DOLLARS)	LEARNING CURVE	ITEM COSTED	REF CER	LEARNING FACTOR	COST OF ITEM (DOLLARS)	NUMBER ITEMS	COST (DOLLARS)
Structure	Stage Propellant Wt. (lbs)	15,300	Ex LV-1	2,900	1,680	4,900,000	90%	150	Ex. LV-8	0.46	2,250,000	1	2,250,000
Propulsion	Engine Thrust (lbs)	16,000	Ex LV-2	—	—	170,000	90%	175	Ex. LV-8	0.45	77,000	1	77,000
Guidance and Control	Weight (lbs)	50	Ex. LV-3	4,600	—	230,000	100%	-	Ex LV-8	1.00	230,000	1	230,000
Transportation Air ☒ Ship or Rail ☐	Stage Dry Weight (lbs)	1,700	Ex. LV-4	—	—	—	—	—	—	—	—	—	200
Acceptance Test	Stage Gross Weight (lbs)	17,000	Ex. LV-5	—	—	—	—	—	—	—	—	—	71,000
Launch Services	L.V. Gross Weight (lbs)	376,000+17,000	Ex. LV-6	—	—	—	—	—	—	—	—	—	1,200,000
Propellants	Propellant Type	RFNA/UDMH	Ex. LV-7	—	—	—	—	—	—	—	0.40/lb	15,300	6,120

TOTAL 3,834,320

1st Stage 7,429,570

L.V. Total 11,263,890 x 1

Other Pertinent Data

Engine Type: Liquid

Engine Dry Weight (ea) (lbs): -

Stage Thrust (lbs): 16,000

TABLE III

SPACECRAFT COST

PROGRAM Mariner IV

MODULE ______

COST CATEGORIES	DESCRIPTION	QUANTIFYING PARMETER	PARAMETER INPUT	REF CER	DESIGN/ DEV'L'PT COST	REF CER	PARAMETER OUTPUT DOLLARS/—	FIRST UNIT COST	NO. TEST ARTICLES	COST OF TEST ARTICLES	NO. FLIGHT ARTICLES	COST OF FLIGHT ARTICLES	TOTAL HROW COST
Structure		Weight (lbs)	162.2	1A	7.05	1B	4,200$/lb	0.681	4	2.724	3	2.043	4.767
Propulsion Module Structure		Weight (lbs)	--	1.1A	--	1.1B							
Entry Structure		Weight (lbs)	--	1A	--	1B							
Propulsion	Liquid	Thrust (lbs)	50.0	2A	1.78	2B	370$/lb	0.020	4	0.08	3	0.060	0.140
Retro-Propulsion	Solid	Weight (lbs)	--	3A		3B							
Navigation and Guidance		Weight (lbs)	48.0	4A	2.70	4B	5,300$/lb	0.254	4	1.016	3	0.762	1.642
Stabilization and Control		Weight (lbs)	53.0	5A	2.90	5B	5,000$/lb	0.266	4	1.064	3	0.798	1.862
Communications		Weight (lbs)	49.5	6A	5.35	6B	6,000$/lb	0.296	4	1.184	3	0.888	2.072
Data Management		Weight (lbs)	49.9	7A	3.15	7B	22,500$/lb	1.122	4	4.488	3	3.366	7.854
Electrical Power		Kilowatts	0.34	8A	3.10	8B	1,300,000$/KW	0.442	4	1.768	3	1.326	3.094
Descent System		Entry Wt. (lbs)	--	9A	--	9B							
Experiments or Mission Sensors		Weight (lbs)	67.0	10A	9.60	10B	7,800$/lb	0.522	4	2.088	3	1.566	3.654
AGE		S/C Dry Wt. (lbs)	574.7	11A	6.80	—							
Tooling and Sp. Test Equipment		S/C Dry Wt. (lbs)	574.7	11A	2.65	—							
TOTALS				▼Σ	45.03	(1)		3.569		14.412	(2)	10.809	25.085
Systems Integration			1 + (2) = $59.49 x 10^6	12A	2.95								

TABLE IV - MARINER IV

SPACECRAFT COST SUMMARY

ITEM		① DESIGN/DEVELOPMENT	② COST OF TEST ARTICLES	③ D/D PLUS TEST ARTICLES	④ INTEGRATION	⑤ COST OF FLIGHT ARTICLES	⑥ TOTAL COST
				① + ②	③ & CER 12A	Dollars, 10^6	③ + ④ + ⑤
Spacecraft Module	1	45.08	14.41	59.49	2.95	10.81	73.25
	2						
	3						
	–	–	–	–	–	–	–
	–	–	–	–	–	–	–
			Σ ⑦	59.49		Σ	73.25
S/C Systems Integration-Increment Ref: ⑦ & CER 12A						⑧	0
					S/C TPC	→ ⑨	73.25

MISSION SUPPORT AND SPACE FLT OPNS	DESCRIPTION / INPUT	REF CER	OPERATION	COST
Program Management		–	0.05 ⑨	3.66
SETD	Mgt Mode/Tech M/P Ratio	15A	K_1 ⑨ where K_1 = 0.04	2.93
Phase A	Adv Studies	–	0.01 ⑨	.73
Phase B	Conceptual Design	–	0.01 ⑨	.73
Phase C	Project Definition, System Design, & Critical Hdw. Dev	–	0.05 ⑨	3.66
Adv. Development	N_R = 0 = Number of High Risk Sub-Systems	–	0.05 ⑨ $(1+\sqrt{N_R})$	3.66
Sterilization	F = - ; W_c/W_s = - ; N = -	13	/100 ⑨ x N/4	--
M.P. Equipment	Mission Peculiar Equipment At SFOF & DSN	14	Z = 0.34	4.90
M.O. Equipment	Mission Operations Training; T = -	–	$0.60 \times 10^6 \times (T+3) + 0.2(MPEC)$	--
Space Flt Opns	Mission Time (T) Months ; T = 7	–	$0.20 \times 10^6 (T+3)$	2.00
Post Flt Analysis	Mission Time (T) Months ; T = 7	–	$0.40 \times 10^6 (T+3)$	4.00
			Subtotal	26.27
Mgt Implen Mode	Mgt Implementation Mode: LAB. MGT.	15	K_2 ⑨ where K_2 = 0	0
Schedule/Program Chg	Nominal Program	16	0/100 ⑨	0
Launch Vehicle				22.53
			1965 DOLLARS	122.05

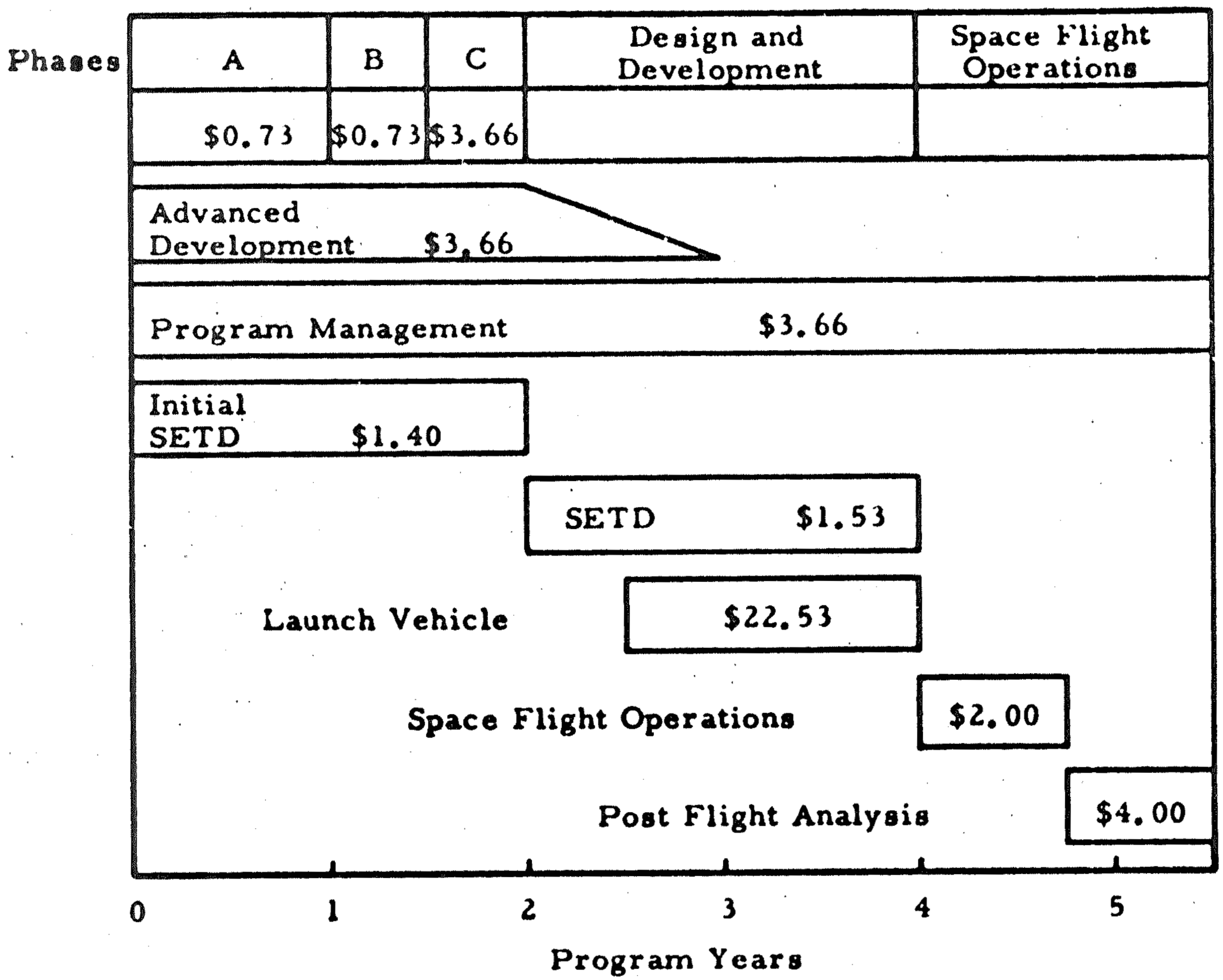


TABLE IVA - MARS MISSION 1964 COSTS IN MILLIONS

2. Mars--Advanced Orbiter/Limited Lander in 1973-1975

TABLE V - DISTRIBUTION OF ADVANCED MISSION WEIGHTS TO COST CATEGORIES, SPACECRAFT BUS (WT. = 3,635 LBS)

Items \ Cost Categories	JPL Weights	Experiments or Mission Sensors	Navigation and Guidance	Communications TT and C	Data Management	Stabilization and Control	Structure	Entry Structure	Propulsion Module Structure	Electrical Power	Descent System	Propulsion	
												Liquid Rocket	Retro Solid
Structure	1,000						1,000						
Thermal Control	100						100						
Radio	154			154									
Command	30			30									
Power	1,015									1,015			
C and S	70		70										
Telemetry	173			173									
Attitude Control	261					261							
Pyrotechnics	36						36						
Cabling	181	30	30	30	30	31	30						
Data Storage	120				120								
Science	495	495											
Totals	3,635	525	100	387	150	292	1,166			1,015			

TABLE VIA - DISTRIBUTION OF ADVANCED MISSION WEIGHTS TO COST CATEGORIES, SPACECRAFT CAPSULE (WT. = 3,000 LBS)

Items \ Cost Categories	JPL Weights	Experiments or Mission Sensors	Navigation and Guidance	Communications TT and C	Data Management	Stabilization and Control	Structure	Entry Structure	Propulsion Module Structure	Electrical Power	Descent System	Propulsion: Liquid Rocket	Propulsion: Retro Solid
Nonseparated Support Equipment	(517)												
Adapter	100						100						
Sterilization Canister Aft Section	73						73						
Capsule Separation Mechanism	15						15						
Umbilical and Cabling	6	1.0	1.0	1.0	1.0	1.0	1.0						
Sterilization Canister Separation Mechanism	10						10						
Thermal Shielding	35						35						
Contingency	278	1.2	1.2	1.2	1.2	1.1	272.1						
Separated Support Equipment	(142)												
Sterilization Canister Fore Section	92						92						
Sterilization Canister Separation Mechanism	10						10						
Sterilization Canister Vent	5						5						
Thermal Shielding	35												
Separated Capsule Subsystem	(596)												
Propulsion	550												550
Propulsion Thrust Structure							26						
Propulsion Separation Mechanism	20						20						

TABLE VIB - DISTRIBUTION OF ADVANCED MISSION WEIGHTS TO COST CATEGORIES, SPACECRAFT CAPSULE (WT. = 3,000 LBS)

Items \ Cost Categories	JPL Weights	Experiments or Mission Sensors	Navigation and Guidance	Communications TT and C	Data Management	Stabilization and Control	Structure	Entry Structure	Propulsion Module Structure	Electrical Power	Descent System	Propulsion: Liquid Rocket	Propulsion: Retro Solid
Entry Capsule Subsystem	(500)												
Aeroshell Structure	167						167						
Aeroshell Heat Shield	159							159					
Paint	12						12						
Capsule Separation Mechanism	15							15					
Entry Subsystem Support Structure	15							15					
Attitude Control System	36					36							
Contingency	96					8.5	42.5	45.0					
Entry Subsystems	(680)												
Sterilization Support	9						9						
Entry Payload	30	30											
Relay Radio	48			48									
Pyrotechnics	18						18						
Power	100									100			
Payload Structure	45						45						
Cabling	50	10		10	10	10	10						
Attitude Control Electronics	24					24							
Temperature Control	20							20					
Sequencer	21			21									
Antenna (2) and Support Structure	24			24									
Altimeter Subsystem	25					25							
Supersonic Parachute	200										200		
Contingency	66	4.3		11.1	1.1	6.4	10.9			10.7	21.5		

TABLE VIC - DISTRIBUTION OF ADVANCED MISSION WEIGHTS TO COST CATEGORIES, SPACECRAFT CAPSULE (WT. = 3,000 LBS)

Items \ Cost Categories	JPL Weights	Experiments or Mission Sensors	Navigation and Guidance	Communications TT and C	Data Management	Stabilization and Control	Structure	Entry Structure	Propulsion Module Structure	Electrical Power	Descent System	Propulsion		
												Liquid Rocket	Retro Solid	
Landed Weight	(565)													
Impact Limiter	255						255							
Impact Limiter Cover	21						21							
Temperature Control	18						18							
Erecting Devices	11						11							
Structure and Cabling	46						46							
Science Subsystem	25	25												
Direct Radio	3			3										
Power Sequencing	40									40				
Power Timing	6			6										
Data Handling	3				3									
Data Storage	8				8									
Pyro and Impact Limiter Removal	4						4							
Subtotals	2,875	71.5		125.3	24.3	112.1	1,196.5	420.7		150.7	221.5		576	= 2,875.1
Contingency	125	3.1		5.5	1.1	4.9	51.1	10.3		6.5	9.6		25	= 125.0
Totals	3,000	74.6		130.8	25.4	117.0	1,247.6	431.0		157.2	231.1		601	3,000.1

TABLE VII - DISTRIBUTION OF ADVANCED MISSION WEIGHTS TO COST CATEGORIES, PROPULSION MODULE (WT. = 15,000 LBS)

Items \ Cost Categories	JPL Weights	Experiments or Mission Sensors	Navigation and Guidance	Communications TT and C	Data Management	Stabilization and Control	Structure	Entry Structure	Propulsion Module Structure	Electrical Power	Descent System	Propulsion	
												Liquid Rocket	Retro Solid
Structure	1,600								1,600				
Engine	400											400	
Totals	2,000								1,600			400	

Item	Weight (lbs)
S/C Bus	3,635
Capsule	3,000
Propulsion Module--Dry	2,000
Total	8,635

$$\text{Sterilization Fraction} = \frac{W_C}{W_{SC}} = \frac{3,000}{8,635} = .348$$

TABLE VIIIA

LAUNCH VEHICLE COST

Saturn S-1C STAGE 1	QUANTIFYING PARAMETER	PARAMETER INPUT	REF. CER	FIRST UNIT COST (DOLLARS/LBS)	STRUCTURE (WT IN LBS)	FIRST UNIT COST (DOLLARS)	LEARNING CURVE	ITEM COSTED	REF CER	LEARNING FACTOR	COST OF ITEM (DOLLARS)	NUMBER ITEMS	COST (DOLLARS)
Structure	Stage Propellant Wt. (lbs)	4,320,000	Ex LV-1	130	323,000	42,000,000	90%	26	Ex. LV-8	0.62	26,000,000	1	26,000,000
Propulsion	Engine Thrust (lbs)	1,500,000	Ex LV-2	—	—	3,700,000	90%	150	Ex. LV-8	0.47	1,740,000	5	8,700,000
Guidance and Control	Weight (lbs)	Not applicable to this stage	Ex. LV-3		—				Ex LV-8				
Transportation Air ☐ Ship or Rail ☒	Stage Dry Weight (lbs)	403,000	Ex. LV-4	—	—	—	—	—	—	—	—	—	10,000
Acceptance Test	Stage Gross Weight (lbs)	4,723,000	Ex. LV-5	—	—	—	—	—	—	—	—	—	1,400,000
Launch Services	L.V. Gross Weight (lbs)	Not applicable to this stage	Ex. LV-6	—	—	—	—	—	—	—	—	—	
Propellants	Propellant Type	LOX-RP-1	Ex. LV-7	—	—	—	—	—	—	—	0.025/lb	4,230,000	108,000
												TOTAL	36,218,000

Other Pertinent Data

Engine Type	Liquid
Engine Dry Weight (ea) (lbs)	16,000
Stage Thrust (lbs)	7.5 M

TABLE VIIIB

LAUNCH VEHICLE COST

Saturn S-II STAGE 2	QUANTIFYING PARAMETER	PARAMETER INPUT	REF. CER	FIRST UNIT COST (DOLLARS/LBS)	STRUCTURE (WT IN LBS)	FIRST UNIT COST (DOLLARS)	LEARNING CURVE	ITEM COSTED	REF CER	LEARNING FACTOR	COST OF ITEM (DOLLARS)	NUMBER ITEMS	COST (DOLLARS)
Structure	Stage Propellant Wt. (lbs)	930,000	Ex LV-1	600	62,600	37,560,000	90%	26th	Ex. LV-8	0.62	23,287,000	1	23,287,000
Propulsion	Engine Thrust (lbs)	200,000	Ex LV-2	—	—	2,400,000	90%	200th	Ex. LV-8	0.44	1,055,000	5	5,275,000
Guidance and Control	Weight (lbs)	Not applicable to this stage	Ex. LV-3		—				Ex LV-8				
Transportation Air ☐ Ship or Rail ☒	Stage Dry Weight (lbs)	80,000	Ex. LV-4	—	—	—	—	—	—	—	—	—	2,000
Acceptance Test	Stage Gross Weight (lbs)	1,010,000	Ex. LV-5	—	—	—	—	—	—	—	—	—	610,000
Launch Services	L.V. Gross Weight (lbs)	Not applicable to this stage	Ex. LV-6	—	—	—	—	—	—	—	—	—	
Propellants	Propellant Type	LOX-LH2	Ex. LV-7	—	—	—	—	—	—	—	0.50/lb	930,000	465,000
												TOTAL	29,639,000

Other Pertinent Data

Engine Type: Liquid

Engine Dry Weight (ea) (lbs): 3,480

Stage Thrust (lbs): 1.0 M

TABLE VIII

LAUNCH VEHICLE COST

Saturn S-IVB STAGE [3]	QUANTIFYING PARAMETER	PARAMETER INPUT	REF. CER	FIRST UNIT COST (DOLLARS/LBS)	STRUCTURE (WT IN LBS)	FIRST UNIT COST (DOLLARS)	LEARNING CURVE	ITEM COSTED	REF CER	LEARNING FACTOR	COST OF ITEM (DOLLARS)	NUMBER ITEMS	COST (DOLLARS)
Structure	Stage Propellant Wt. (lbs)	216,000	Ex LV-1	820	21,520	17,600,000	90%	30th	Ex. LV-8	0.565	9,930,000	1	9,930,000
Propulsion	Engine Thrust (lbs)	200,000	Ex LV-2	—	—	2,400,000	90%	200th	Ex. LV-8	0.44	1,055,000	1	1,055,000
Guidance and Control	Weight (lbs)	4,000	Ex. LV-3	1,000	—	4,000,000	90%	30th	Ex LV-8	0.565	2,260,000	1	2,260,000
Transportation Air [X] Ship or Rail [ ]	Stage Dry Weight (lbs)	25,000	Ex. LV-4	—	—	—	—	—	—	—	—	—	3,000
Acceptance Test	Stage Gross Weight (lbs)	241,000	Ex. LV-5	—	—	—	—	—	—	—	—	—	235,000
Launch Services	L.V. Gross Weight (lbs)	5,922,000	Ex. LV-6	—	—	—	—	—	—	—	—	—	3,000,000
Propellants	Propellant Type	LOX-LH_2	Ex. LV-7	—	—	—	—	—	—	—	0.50/lb	216,000	180,000

TOTAL	16,591,000
Stage 2	29,639,000
Stage 3	36,218,000
L. V. Total	82,448,000

Other Pertinent Data

Engine Type [Liquid]

Engine Dry Weight (e3) (lbs) [3,480]

Stage Thrust (lbs) [200,000]

TABLE IXA

SPACECRAFT COST

PROGRAM Mars Advanced Orbiter/Limited Lander

MODULE Spacecraft Bus

COST CATEGORIES	DESCRIPTION	QUANTIFYING PARMETER	PARAMETER INPUT	REF CER	DESIGN/ DEV'L'PT COST	REF CER	PARAMETER OUTPUT DOLLARS/—	FIRST UNIT COST	NO. TEST ARTICLES	COST OF TEST ARTICLES	NO. FLIGHT ARTICLES	COST OF FLIGHT ARTICLES	TOTAL HROW COST
Structure		Weight (lbs)	1,166	1A	16.20	1B	1,410$/lb	1.643	5	8.215	4	6.572	14.787
Propulsion Module Structure		Weight (lbs)		1.1A		1.1B							
Entry Structure		Weight (lbs)		1A		1B							
Propulsion	Liquid	Thrust (lbs)		2A		2B							
Retro-Propulsion	Solid	Weight (lbs)		3A		3B							
Navigation and Guidance		Weight (lbs)	100	4A	4.60	4B	4,350$/lb	0.435	5	2.175	4	1.740	3.915
Stabilization and Control		Weight (lbs)	292	5A	5.10	5B	3,100$/lb	0.905	5	4.525	4	3.620	8.145
Communications		Weight (lbs)	387	6A	25.50	6B	5,500$/lb	2.150	5	10.750	4	8.600	19.350
Data Management		Weight (lbs)	150	7A	6.00	7B	15,100$/lb	2.260	5	11.300	4	9.040	20.340
Electrical Power		Kilowatts	0.20	8A	17.50	8B	8,700,000$/KW x 6 units	10.440	1	10.440	4	41.760	52.200
Descent System		Entry Wt. (lbs)	--	9A	--	9B							
Experiments or Mission Sensors		Weight (lbs)	525	10A	25.00	10B	5,000$/lb		5	13.100	4	10.480	23.580
AGE		S/C Dry Wt. (lbs)	3,635	11A	22.3	—							
Tooling and Sp. Test Equipment		S/C Dry Wt. (lbs)	3,635	11A	9.6	—							
TOTALS				▼Σ	131.80	(1)		20.243		60.505	(2)	81.802	142.317
Systems Integration			(1) + (2) = $192.305 x 10^6	12A	9.40								

TABLE IXB

SPACECRAFT COST

PROGRAM Mars Advanced Orbiter/Limited Lander

MODULE Entry Capsule

COST CATEGORIES	DESCRIPTION	QUANTIFYING PARMETER	PARAMETER INPUT	REF CER	DESIGN/ DEV'L'PT COST	REF CER	PARAMETER OUTPUT DOLLARS/—	FIRST UNIT COST	NO. TEST ARTICLES	COST OF TEST ARTICLES	NO. FLIGHT ARTICLES	COST OF FLIGHT ARTICLES	TOTAL HRDW COST
Structure		Weight (lbs)	1,247.6	1A	16.70	1B	1,800$/lb	2.243	5	11.215	4	8.972	20.187
Propulsion Module Structure		Weight (lbs)		1.1A		1.1B							
Entry Structure		Weight (lbs)	431.0	1A	22.60	1B	3,200$/lb	1.380	5	6.900	4	5.520	12.420
Propulsion	Liquid	Thrust (lbs)		2A		2B							
Retro-Propulsion	Solid	Weight (lbs)	601.0	3A	5.27	3B	510$/lb	0.307	5	1.535	4	1.228	2.763
Navigation and Guidance		Weight (lbs)		4A		4B							
Stabilization and Control		Weight (lbs)	117.0	5A	3.75	5B	4,050$/lb	0.474	5	2.370	4	1.896	4.266
Communications		Weight (lbs)	130.8	6A	11.10	6B	5,800$/lb	0.760	5	3.800	4	3.040	6.840
Data Management		Weight (lbs)	25.4	7A	2.10	7B	27,000$/lb	0.685	5	3.425	4	2.740	6.165
Electrical Power	Fuel Cell	Kilowatts	0.10	8A	1.10	8B	1,500,000$/KW	0.150	5	0.750	4	0.600	1.350
Descent System		Entry Wt. (lbs)	17.45	9A	10.90	9B	52$/lb	0.091	5	0.455	4	0.364	0.819
Experiments or Mission Sensors		Weight (lbs)	74.60	10A	10.00	10B	7,500$/lb	0.560	5	2.800	4	2.240	5.040
AGE		S/C Dry Wt. (lbs)	3,000	11A	19.00	—							
Tooling and Gp. Test Equipment		S/C Dry Wt. (lbs)	3,000	11A	8.40	—							
TOTALS				▼Σ	110.92	1		6.65		33.25	2	26.60	58.85
Systems Integration			1 + 2 = 144.17×10^6	12A	7.20								

TABLE IXC

SPACECRAFT COST

PROGRAM Mars Advanced Orbiter/Limited Lander

MODULE Propulsion Module

COST CATEGORIES	DESCRIPTION	QUANTIFYING PARMETER	PARAMETER INPUT	REF CER	DESIGN/ DEV'L'PT COST	REF CER	PARAMETER OUTPUT DOLLARS/—	FIRST UNIT COST	NO. TEST ARTICLES	COST OF TEST ARTICLES	NO. FLIGHT ARTICLES	COST OF FLIGHT ARTICLES	TOTAL HROW COST
Structure		Weight (lbs)	1,600	1A	32.50	1B	2,800$/lb	4.480	5	22.400	4	17.920	40.32
Propulsion Module Structure		Weight (lbs)		1.1A		1.1B							
Entry Structure		Weight (lbs)		1A		1B							
Propulsion	Liquid	Thrust (lbs)	12,000	2A	6.40	2B	16.1$/lb	0.193	5	0.965	4	0.772	1.737
Retro-Propulsion	Solid	Weight (lbs)		3A		3B							
Navigation and Guidance		Weight (lbs)		4A		4B							
Stabilization and Control		Weight (lbs)		5A		5B							
Communications		Weight (lbs)		6A		6B							
Data Management		Weight (lbs)		7A		7B							
Electrical Power		Kilowatts		8A		8B							
Descent System		Entry Wt. (lbs)		9A		9B							
Experiments or Mission Sensors		Weight (lbs)		10A		10B							
AGE		S/C Dry Wt. (lbs)	2,000	11A	14.70	—							
Tooling and Sp Test Equipment		S/C Dry Wt. (lbs)	2,000	11A	6.30	—							
TOTALS				▼Σ	59.90	1		4.673		23.365	2	18.692	42.057
Systems Integration			1 + 2 = 78.59 x 10^6	12A	3.95								

TABLE X - MARS ADVANCED ORBITER/LIMITED LANDER

SPACECRAFT COST SUMMARY

ITEM		(1) DESIGN/DEVELOPMENT	(2) COST OF TEST ARTICLES	(3) D/D PLUS TEST ARTICLES	(4) INTEGRATION	(5) COST OF FLIGHT ARTICLES	(6) TOTAL COST
				(1) + (2)	(3) f CER 12A	Dollars, 10^6	(3) + (4) + (5)
Spacecraft Module	1	131.80	60.51	192.31	9.40	81.80	283.51
	2	110.92	33.25	144.17	7.20	26.60	177.97
	3	59.90	23.37	83.27	4.30	18.69	106.26
	—	—	—	—	—	—	—
	—	—	—	—	—	—	—
			Σ (7)			Σ	567.74
S/C Systems Integration-Increment Ref: (7) & CER 12A		—	—	—	—	(8)	8.30
		—	—	—	S/C TPC	→ (9)	576.04

MISSION SUPPORT AND SPACE FLT OPNS	DESCRIPTION / INPUT	REF CER	OPERATION	COST
Program Management		—	0.05 (9)	28.80
SETD	Mgt Mode/Tech M/P Ratio	15A	K_1 (9) where $K_1 = 0.07$	40.32
Phase A	Adv Studies	—	0.01 (9)	5.76
Phase B	Conceptual Design	—	0.01 (9)	5.76
Phase C	Project Definition, System Design, & Critical Hdw. Dev	—	0.05 (9)	28.80
Adv. Development	N_R = 3 = Number of High Risk Sub-Systems	—	0.05 (9) $(1+\sqrt{N_R})$	78.70
Sterilization	F = 5 ; W_c/W_s = .348 ; N = 4	13	13.42/100 (9) x N/4	80.20
M.P. Equipment	Mission Peculiar Equipment At SFOF & DSN	14	Σ = .96	15.00
M.O. Equipment	Mission Operations Training; T = 7	—	$0.60 \times 10^6 \times (T+3) + 0.2(MPEC)$	9.00
Space Flt Opns	Mission Time (T) Months ; T = 7	—	$0.20 \times 10^6 (T+3)$	2.00
Post Flt Analysis	Mission Time (T) Months ; T = 7	—	$0.40 \times 10^6 (T+3)$	4.00
			Subtotal	298.34
Mgt Implen Mode	Mgt Implementation Mode: SYS MGT	15	K_2 (9) where K_2 = -0.07	-40.32
Schedule/Program Chg	Parallel Development	16	22.0/100 (9)	126.72
Launch Vehicle				82.45
			1965 DOLLARS	1,043.23

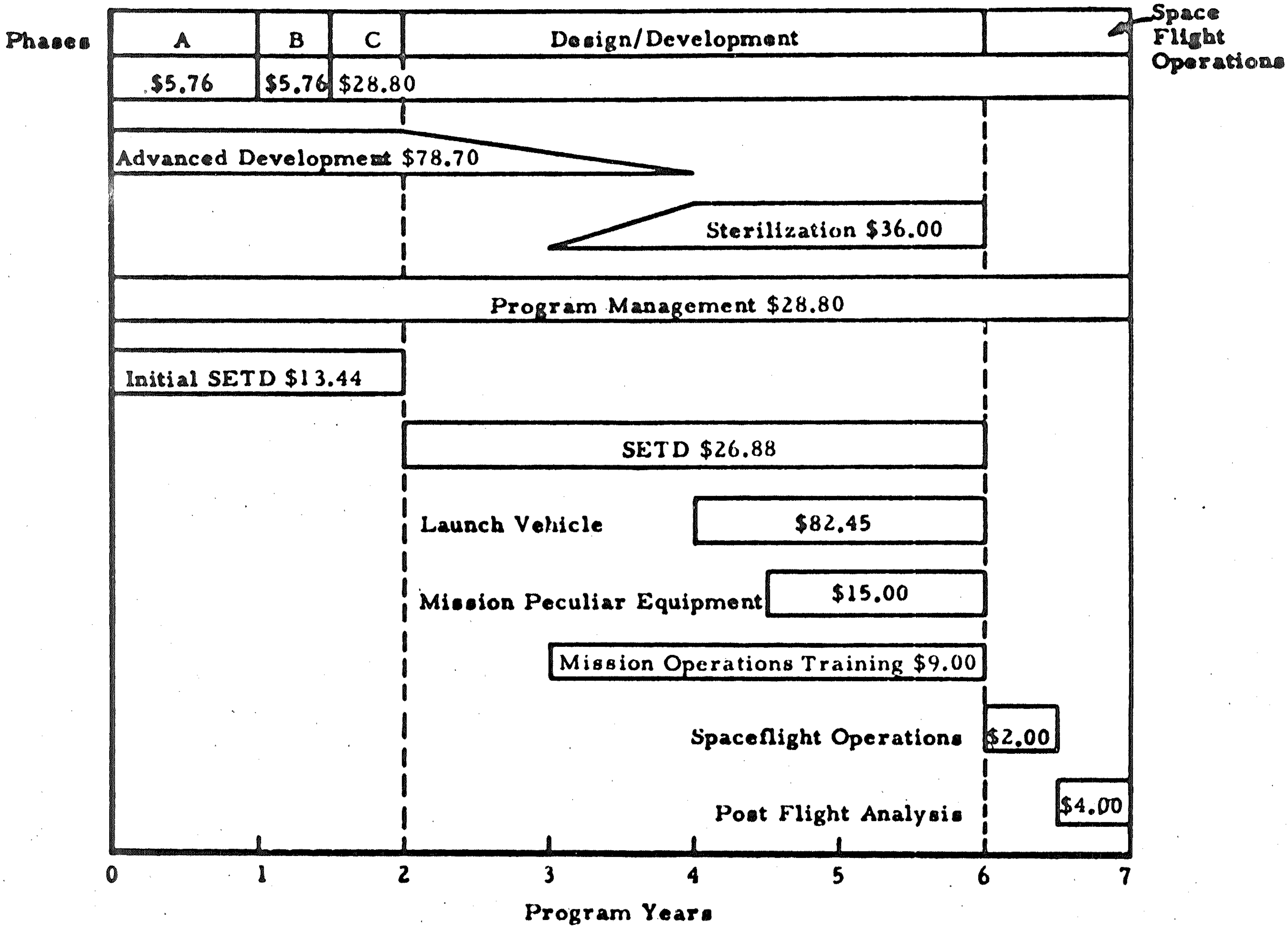


TABLE XA - MARS ADVANCED ORBITER/LIMITED LANDER NOMINAL PROGRAM (ALL COSTS IN MILLIONS)

F. Scope and Accuracy of the Cost Model

The launch vehicle costs were considered as procurement costs only with the cost of any development considered to be negligible or inherited from other programs. Solid rockets were not considered.

The liquid rocket stages considered were LOX/RP-1 and LOX/LH_2. It is felt that the use of Exhibit LV-1 for the cost of LOX/RP-1 stages will result in an error not to exceed ± 10 percent; but that the use of the cost curve for LOX/LH_2 stages will result in an error on the low side between zero and 44 percent in the region of propellant weights of 1,000,000 pounds and greater. The reason for this error is traceable to meager data points and the influence of one particular program. For the Saturn V Launch Vehicle cost, the cumulative error (on the low side), considering all three stages, is estimated not to exceed 18 percent.

Within the spacecraft subsystem cost categories, the error in Design/Development costs is estimated at ±40 to 45 percent, whereas the first unit costs are estimated to be ±25 to 30 percent. The reason for the greater errors in Design/Development costs are largely twofold: (1) meager data in segregating Design/Development costs; and (2) the difficulty in quantifying the impact of inherited development from past programs.

With regard to size of spacecraft to be costed by this method, it is felt that the costing errors stated above increase substantially if the total dry weight of the spacecraft is less than 150 to 200 pounds or more than 10,000 to 12,000 pounds.

Whereas the distribution of costs to Design/Development and first unit costs were engineering judgments in some of the past programs analyzed, the total program costs are estimated to be in error by not more than ±25 percent.

The costs shown in this report are based on 1965 dollars. For future years, the costs obtained from this model should be escalated by three percent per year since 1965.

G. Recommendations for Future Cost Accounting

Part of the purpose of a cost model is to establish a framework for evaluating and displaying data on future spacecraft programs. As mentioned previously in subsection II. B, the initial cost categories chosen are closely related to the quantity of cost data available in these categories; however, it seems appropriate to make some recommendations for future cost accounting at this time.

As the size of unmanned spacecraft programs grows, it appears particularly important to establish new cost categories as follows for both the launch vehicle and spacecraft:

- o Design
- o Fabricate and Assemble Test Hardware
- o Fabricate and Assemble Flight Hardware
- o Ground Development Testing
- o Space Flight Operations

It is also suggested that these categories be used within each subsystem and related activities where appropriate--for example:

Utilization of Cost Categories

Spacecraft Subsystem	Data Management	AGE*	Tooling and Special Test Equipment*
Design	Yes	Yes	Yes
Fabricate and Assemble Test Hardware	Yes	Yes	Yes
Fabricate and Assemble Flight Hardware	Yes	No	Yes
Ground Development Testing	Yes	Yes	Yes
Space Flight Operations	No	No	Yes, for mission peculiar equipment at SFOF

* For Data Management

In this way, design costs can be segregated from ground testing, and the level of ground testing and its influence on subsequent reliability achievement assessed.

RE-ORDER No. 66-664

APPENDIX

STANDARDIZED COST FORMS AND COST ESTIMATING RELATIONSHIPS

Definition of Terms Used in the Cost Estimating Relationships (CER)

Structure

The structure consists of the main load carrying members, the outer skin, adapters, thermal control louvres and shields, solar panels, supporting structure for various instruments, mechanisms, actuators for unmanned unpressurized spacecraft.

The propulsion module structure is principally the tank or pressure vessel for the propellants named.

The entry vehicle structure is the entire aero-shell structure including the heat shield, shingles and supporting structure.

Propulsion

The propulsion module engines are liquid rockets and their associated turbo-pumps, valves, thrust vector controls and plumbing. The retrorockets are small solid rockets including the case with no thrust vector controls.

Navigation and Guidance

The navigation and guidance system costs shown apply to inertial systems and radio command systems and consist of such items as the central computer and sequencer (CC and S), stellar navigation sensors, inertial platforms, accelerometers, and the command system and associated electronics.

Stabilization and Control

This subsystem consists largely of the attitude control systems such as momentum storage, gravity gradient and cold gas systems and include such items as gas storage tanks, reaction jets, valves, servo-valves, gyroscopes, momentum wheels, star and planet seekers, associated electronics and intercommecting cabling.

Communications

Communication subsystems have been divided into two categories, tracking, telemetry and command (TT and C) and relay. Tracking, telemetry and command has been defined to include the beacons used to aid radar tracking, the transmission of all data from primary mission sensors, the telemetry of engineering data and the command receivers used to control the functions of the spacecraft. Relay communications include only those systems or portions of systems used to receive and re-transmit messages originating outside the spacecraft.

Data Management

This subsystem consists of the data encoder, data storage and related cabling.

Solar Cell Electrical Power

The silicon solar cell has been, and remains, the major source of electrical power for spacecraft. The appreciable cost of assembly and interconnection may be reduced by using the larger 2 x 2 cm. cells now being offered in addition to the standard 1 x 2 size. Still greater economy may be available when flexible, film arrays become available. While present systems all use the same photovoltaic mechaniem, two mounting methods, body mounted and fixed and moveable paddles, are used, leading to different costs. Two separate curves are provided for Design/Development costs to reflect the differences between the paddle and body mounted approaches while one consolidated curve has been presented for first unit costs.

RE-ORDER No. 66-664

Solar Dynamic Electrical Power

The principal system presently under development for the dynamic conversion of solar energy is the Brayton cycle using an inert gas to drive a turbo-generator. The design of a solar concentrator, heat receiver and storage unit continues to be a problem. No operational space system reference points are available for these systems. The Stirling cycle piston engine has shown some promise also.

Fuel Cells Electrical Power

The present state of the art in fuel cells is defined by the status of the three major development programs:

1. An ion exchange membrane
2. A modified Bacon cell
3. A low temperature system using an asbestos matrix

In all three the fuel is hydrogen and oxygen and the by-products are water and heat. The exhibits show typical costs for such systems.

Isotope (RTG) Electrical Power

Isotope fueled thermoelectric power supplies are currently receiving most of the development funding for nuclear power systems. Primarily two fuels are being considered, Plutonium 238 (half life 86 years) for long lifetime missions and Polonium 210 (half life 139 days) for short missions. Despite its high cost Plutonium 238 is considered for the longer duration missions. The difference in fuel cost is reflected in the exhibit for first unit cost where two curves are shown for the two fuels. Only one curve is shown in the Design/Development exhibit since the development costs are essentially independent of the particular isotope fuel used.

Nuclear Reactor Electrical Power

The three basic nuclear reactor power conversion systems are thermoelectric, thermionic and turbogenerator. At the higher power levels where all the attention was once concentrated on the turbo generator systems, the thermionic systems are now being considered. At the lower power levels the thermoelectric systems are considered due to their apparent longer life and higher reliability due to the absence of moving parts.

Batteries

The costs shown refer to silver-zinc batteries. The Design/Development costs are insignificant and are therefore omitted. Since these batteries have been produced for some time in large quantities current costs reflect production efficiencies and no learning curve considerations will lower the costs appreciably.

Descent System

The descent system refers to parachutes, attachment fitings, and containers only. The Design/Development costs vary considerably with the Mach number and altitude of the parachute deployment due principally to the cost of simulating the test conditions. The first unit costs are not sensitive to these test conditions within the ranges of values considered.

Mission Sensors

The mission sensors (or experiments) considered here refer to TV systems, IR systems, UV telescopes, magnetometers, IR spectometers and other instruments to support particular experiments.

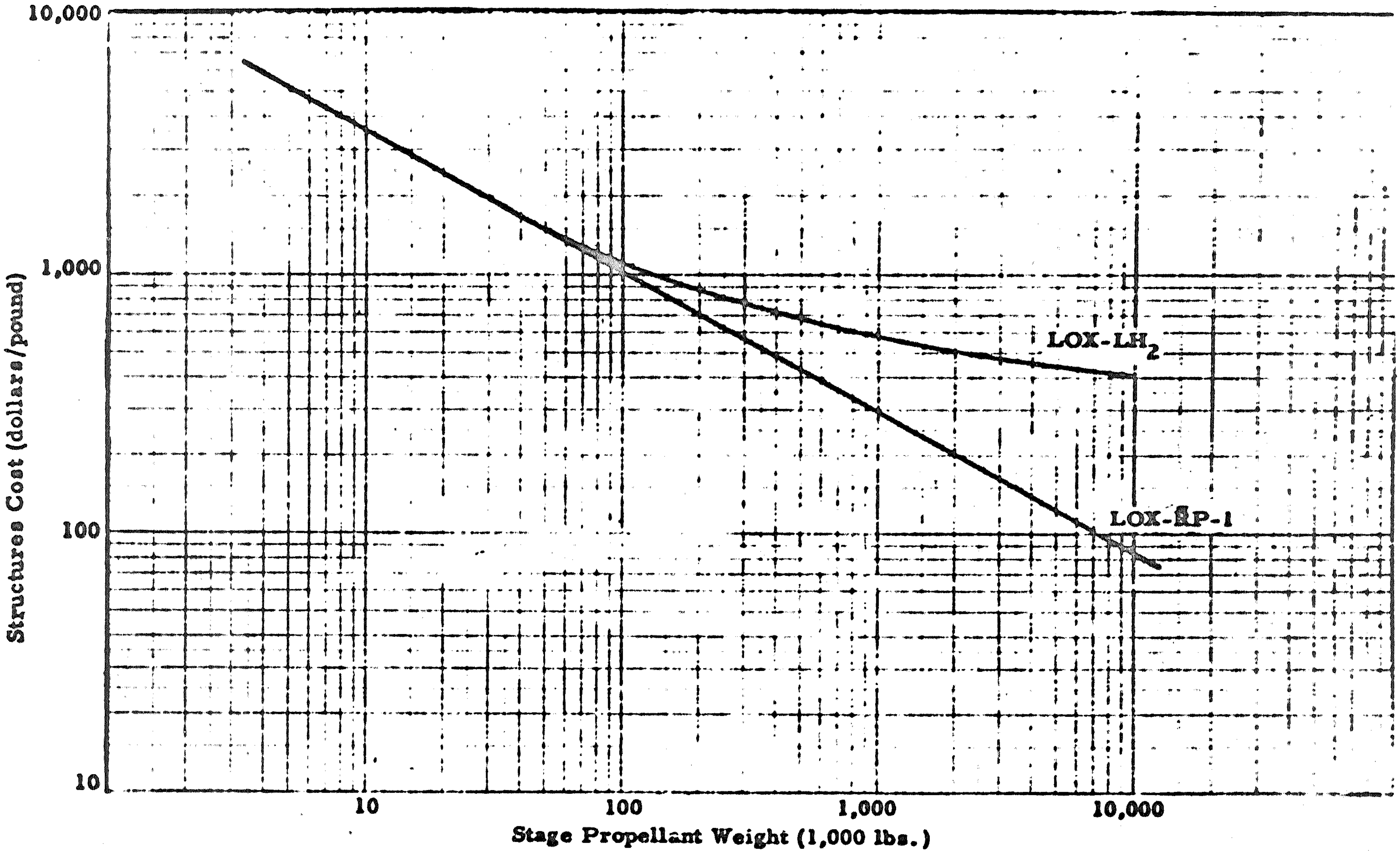


EXHIBIT LV-1 LIQUID STAGE STRUCTURE 1ST UNIT COST

RE-ORDER No. 66-66

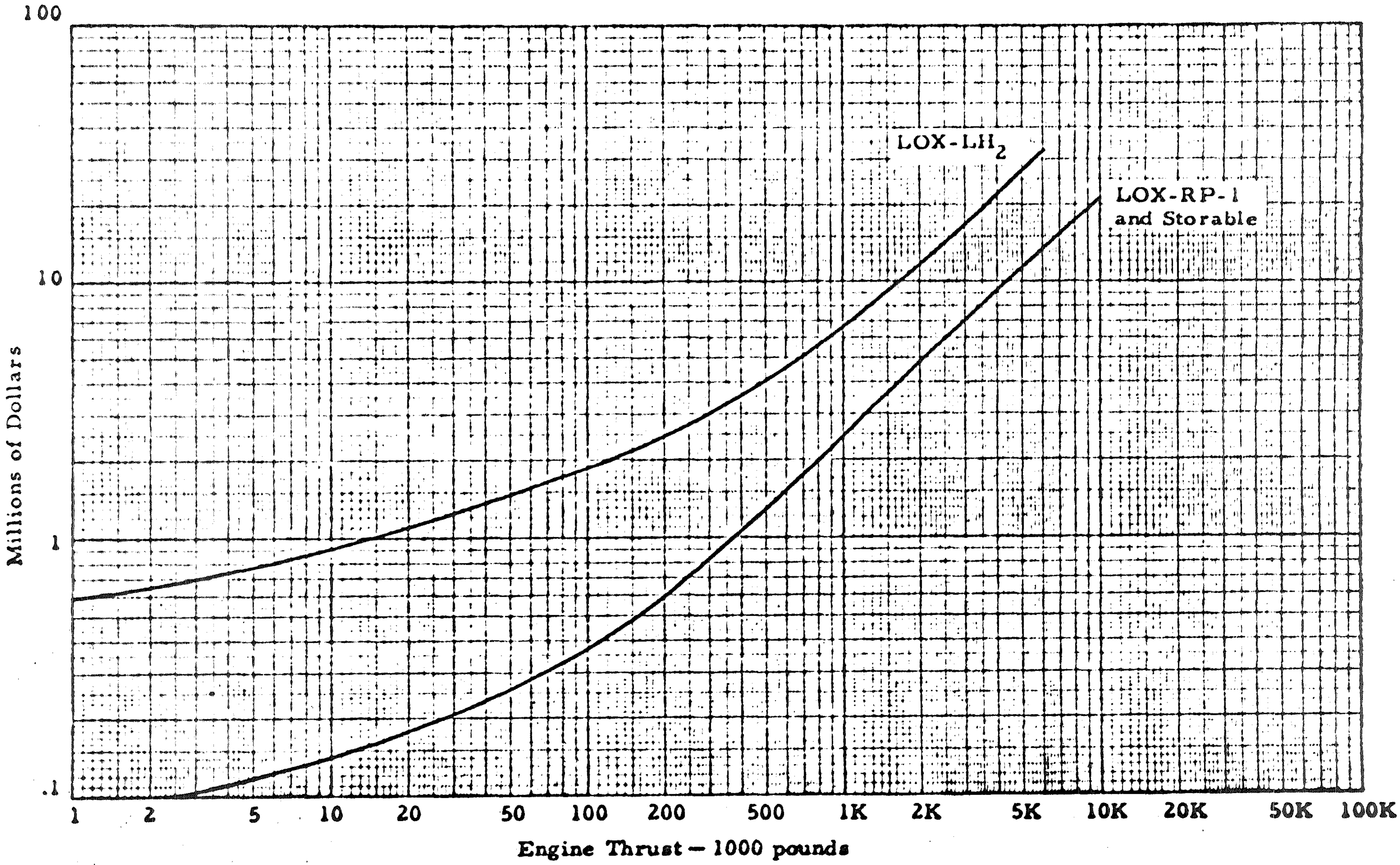


EXHIBIT LV-2 LIQUID ENGINES FIRST UNIT COST

RE-ORDER No. 66-664

54

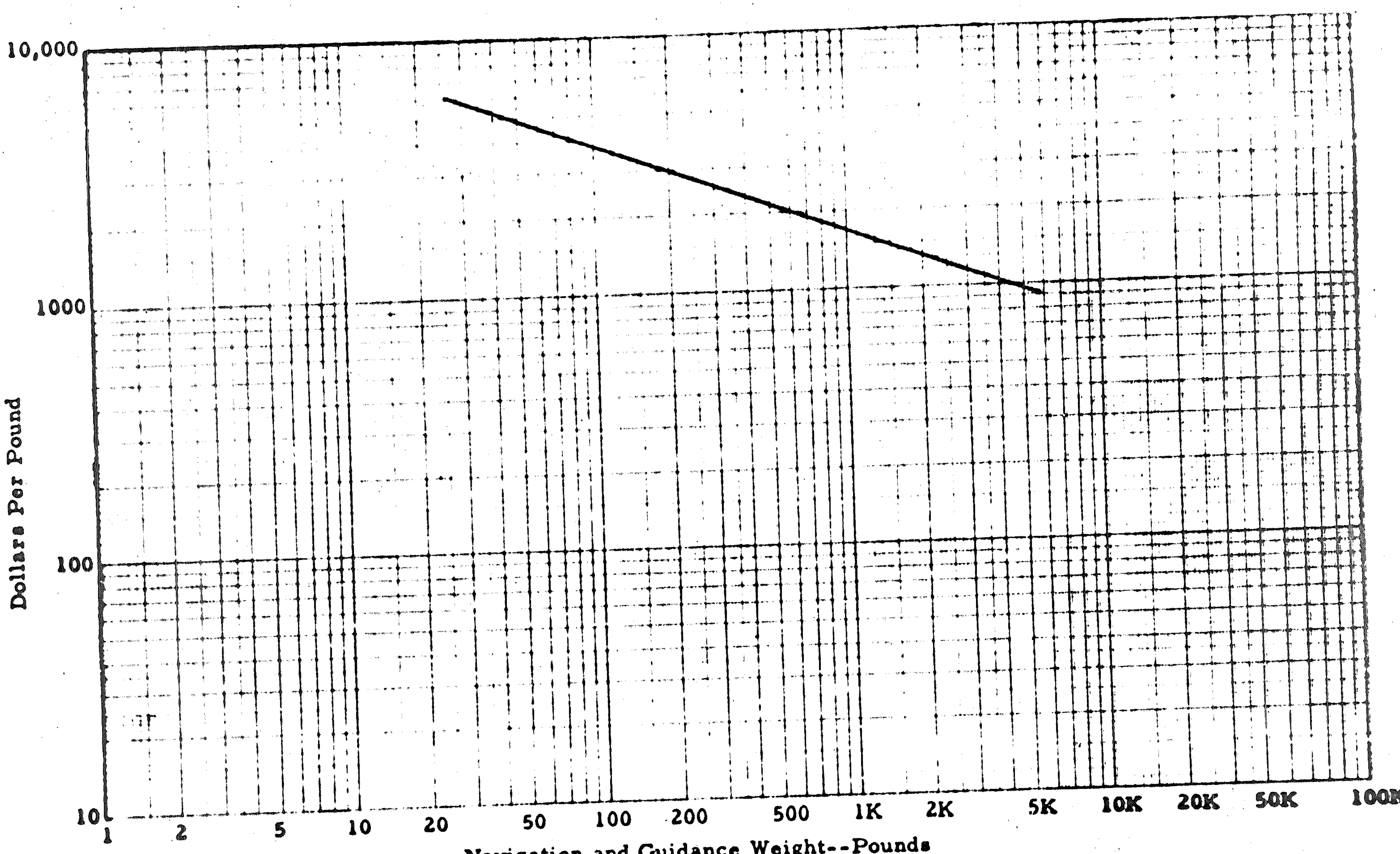


EXHIBIT LV-3 NAVIGATION AND GUIDANCE FIRST UNIT COST

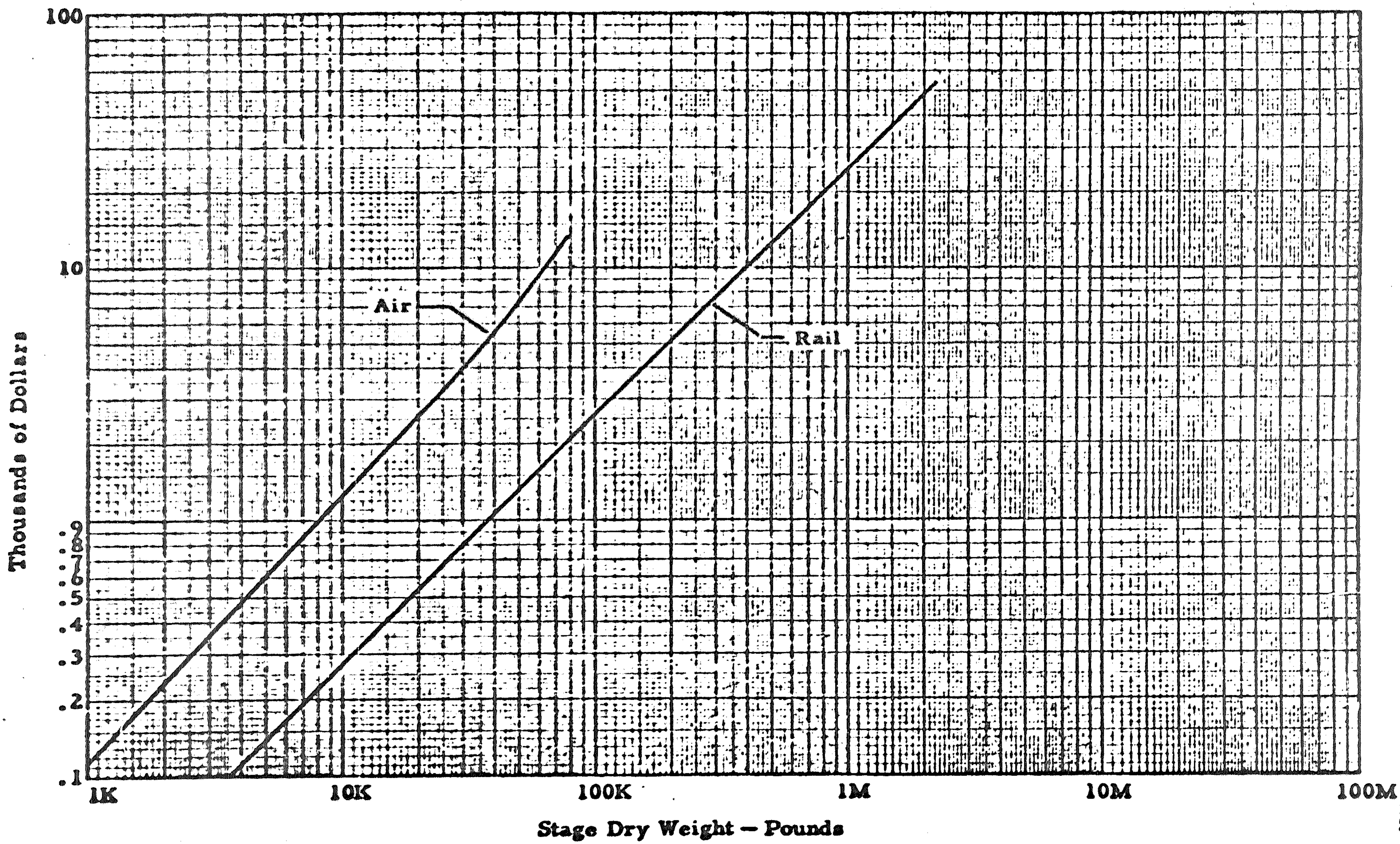


EXHIBIT LV-4 TRANSPORTATION COST PER TRIP

RE-ORDER No. 66-664

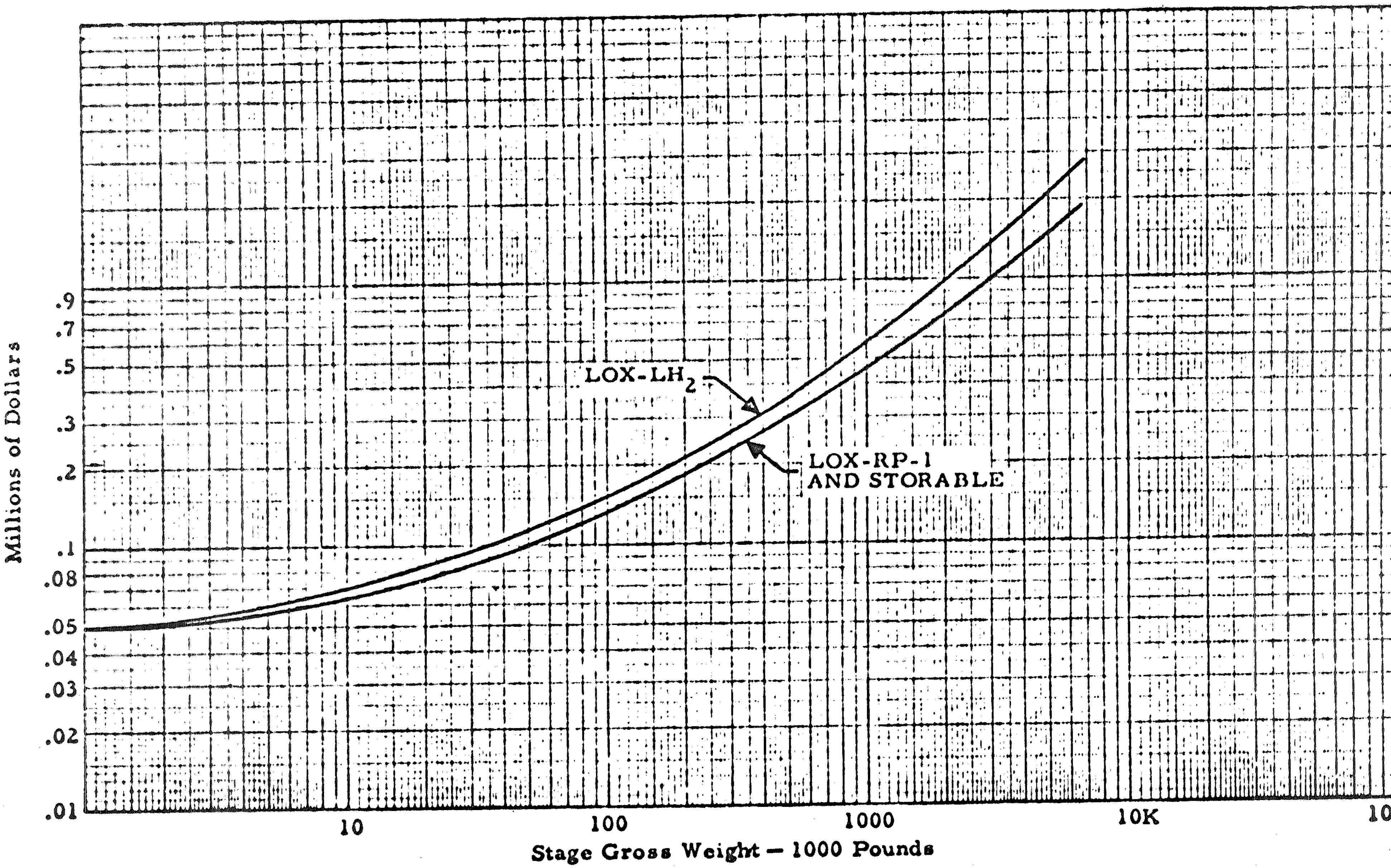


EXHIBIT LV-5 COST FOR ACCEPTANCE TEST PER STAGE AND VEHICLE

RE-ORDER No. 66-664

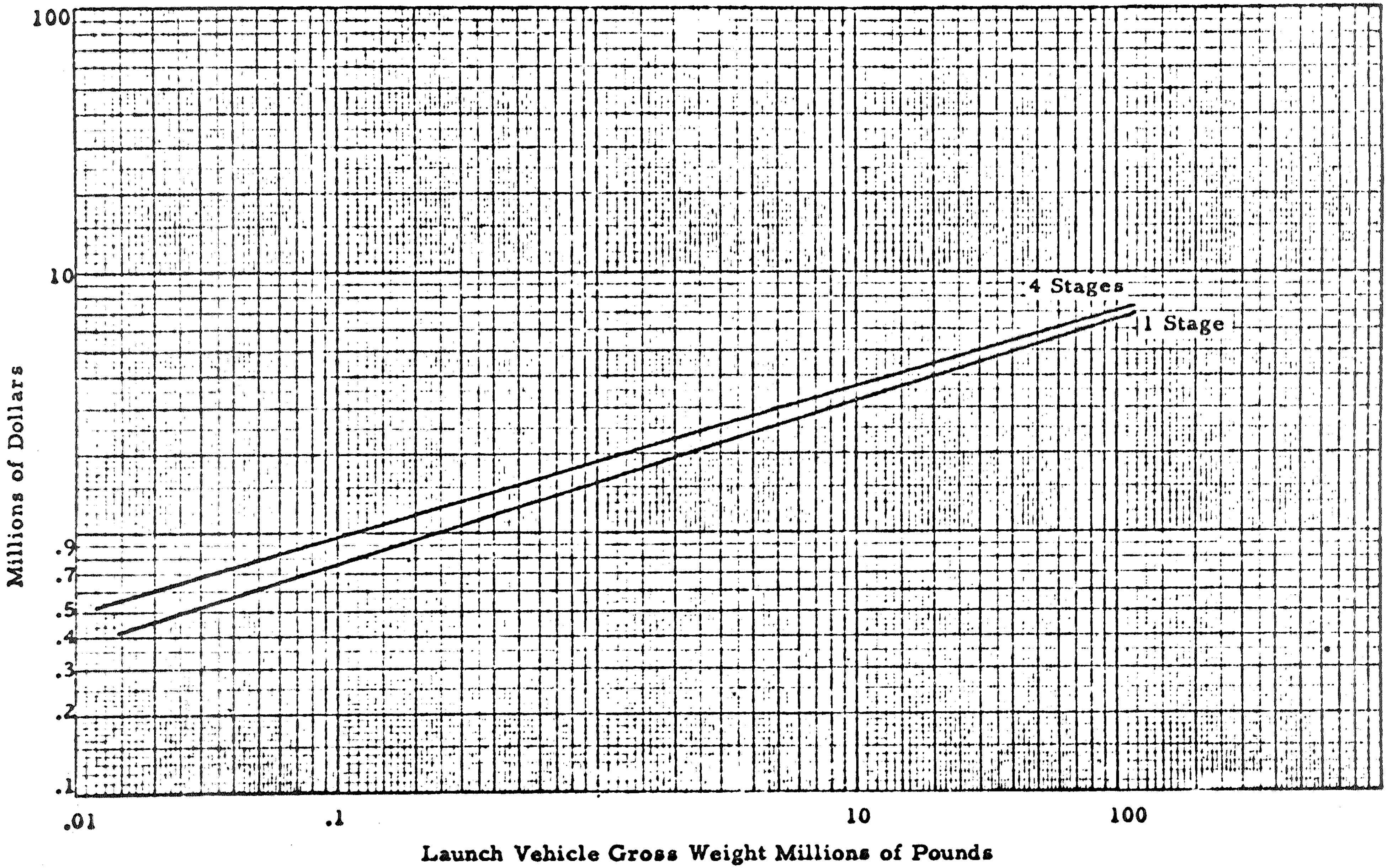


EXHIBIT LV-6 LAUNCH SERVICES COST PER LAUNCH

RE-ORDER No. 66-664

58

EXHIBIT LV-7 LAUNCH VEHICLE PROPELLANT COST

Propellant Type	Cost/Pound
Storable	$0.400
LOX-LH_2	0.500
LOX-RP-1	0.025

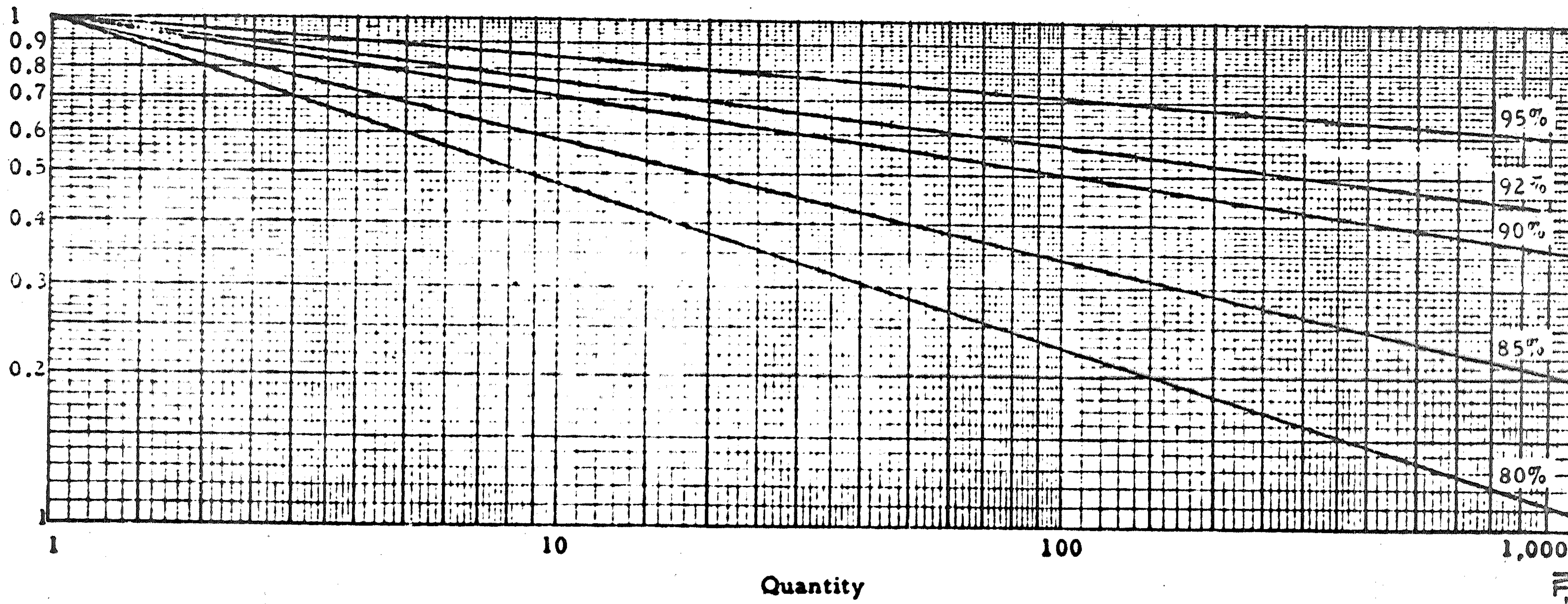


EXHIBIT LV-8 UNIT LEARNING CURVE

RE-ORDER No. 66-664

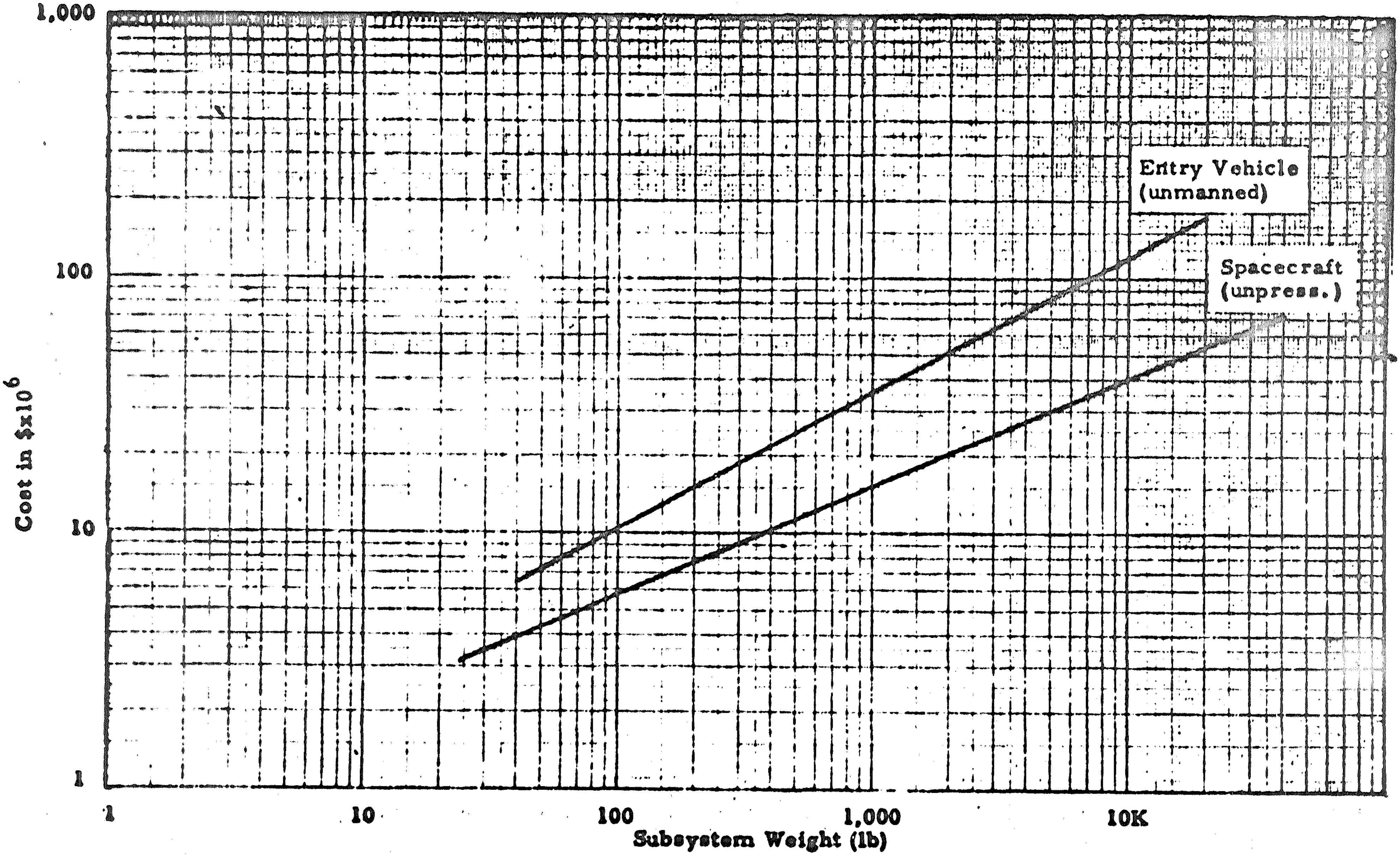


EXHIBIT 1A - SPACE VEHICLE STRUCTURE DESIGN/ DEVELOPMENT COSTS

RE-ORDER No. 66-664

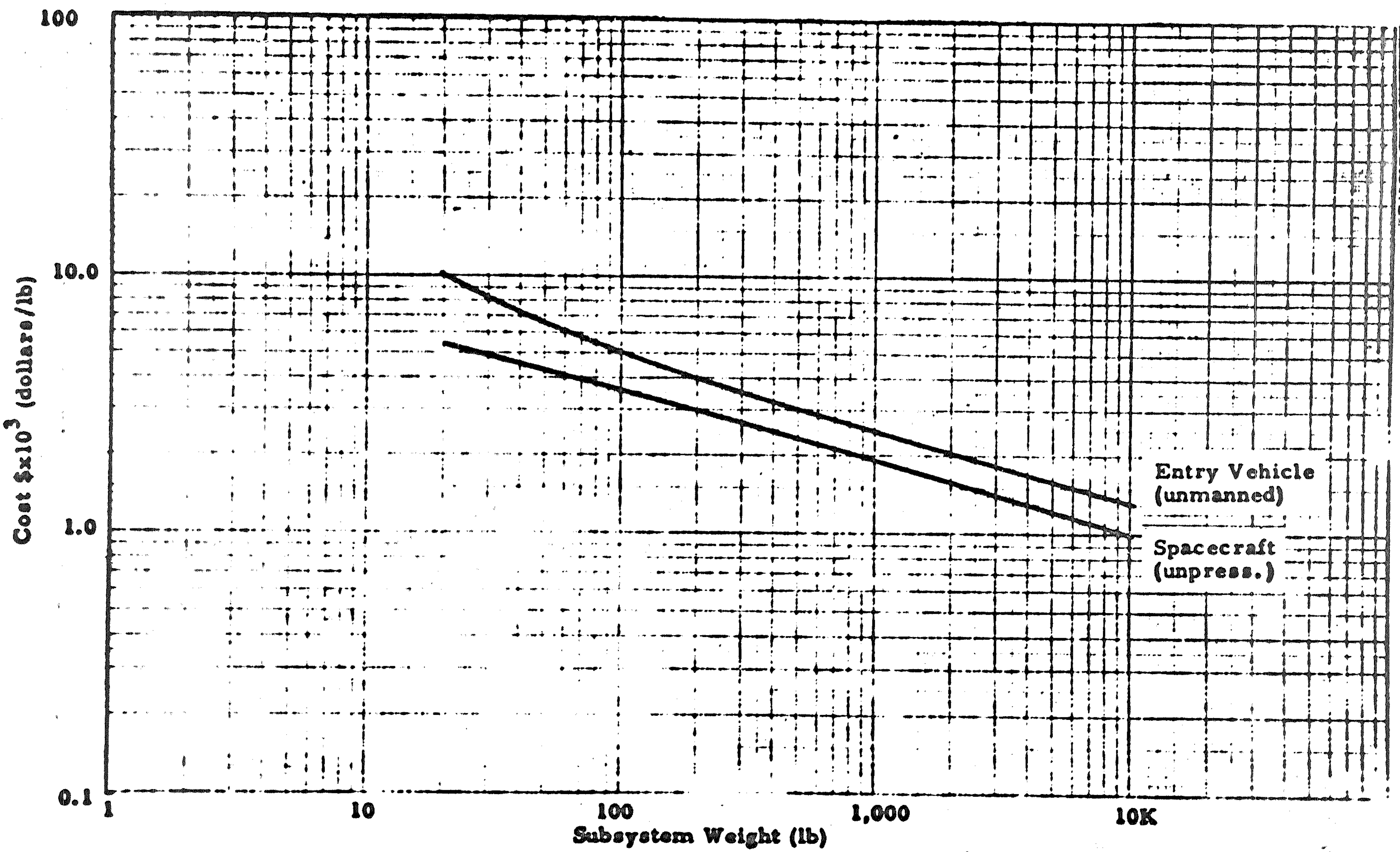


EXHIBIT 1B - SPACE VEHICLE STRUCTURE FIRST UNIT COSTS

RE-ORDER No. 66-664

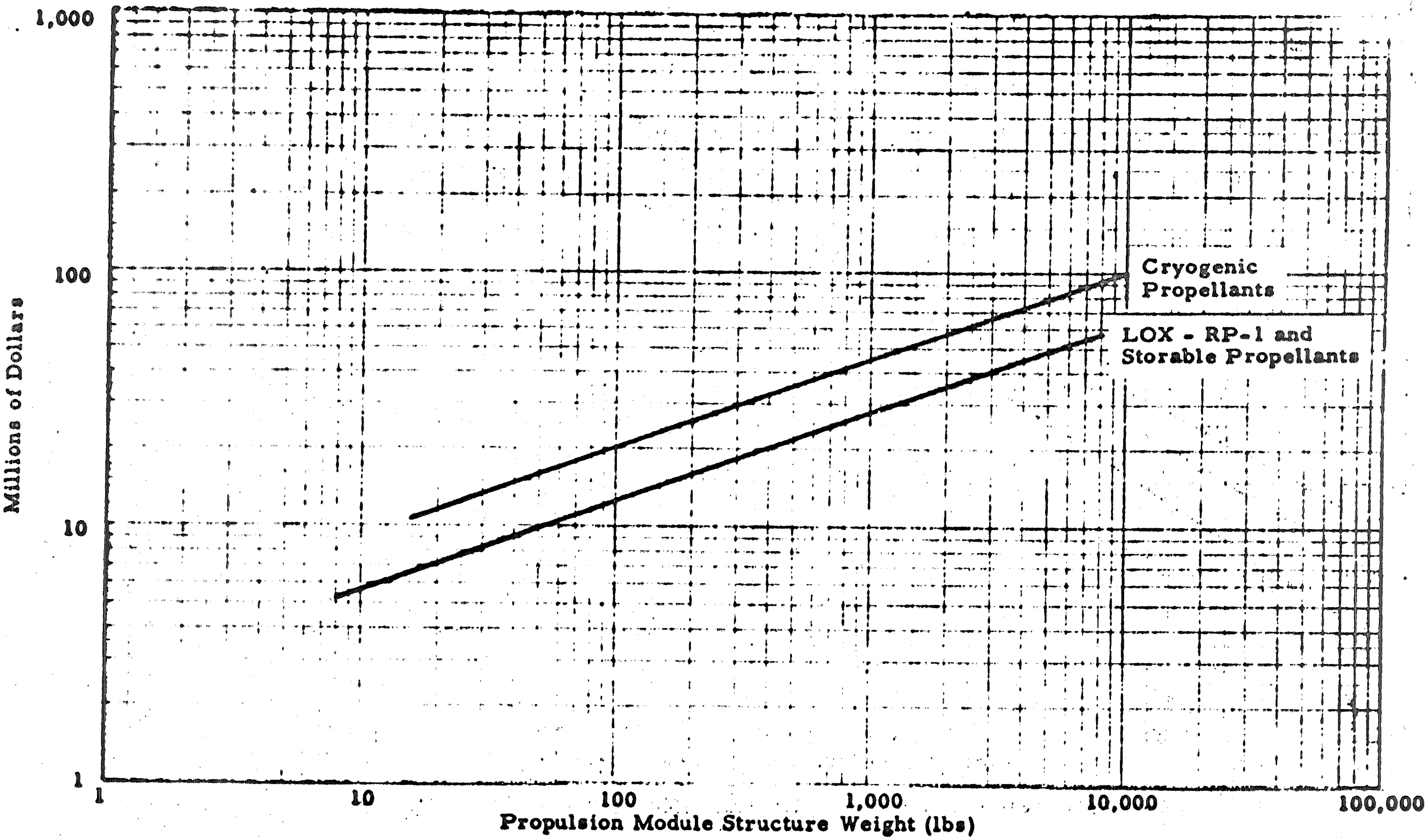


EXHIBIT 1.1A - PROPULSION MODULE STRUCTURE DESIGN/DEVELOPMENT COST

RE-ORDER No. 66-664

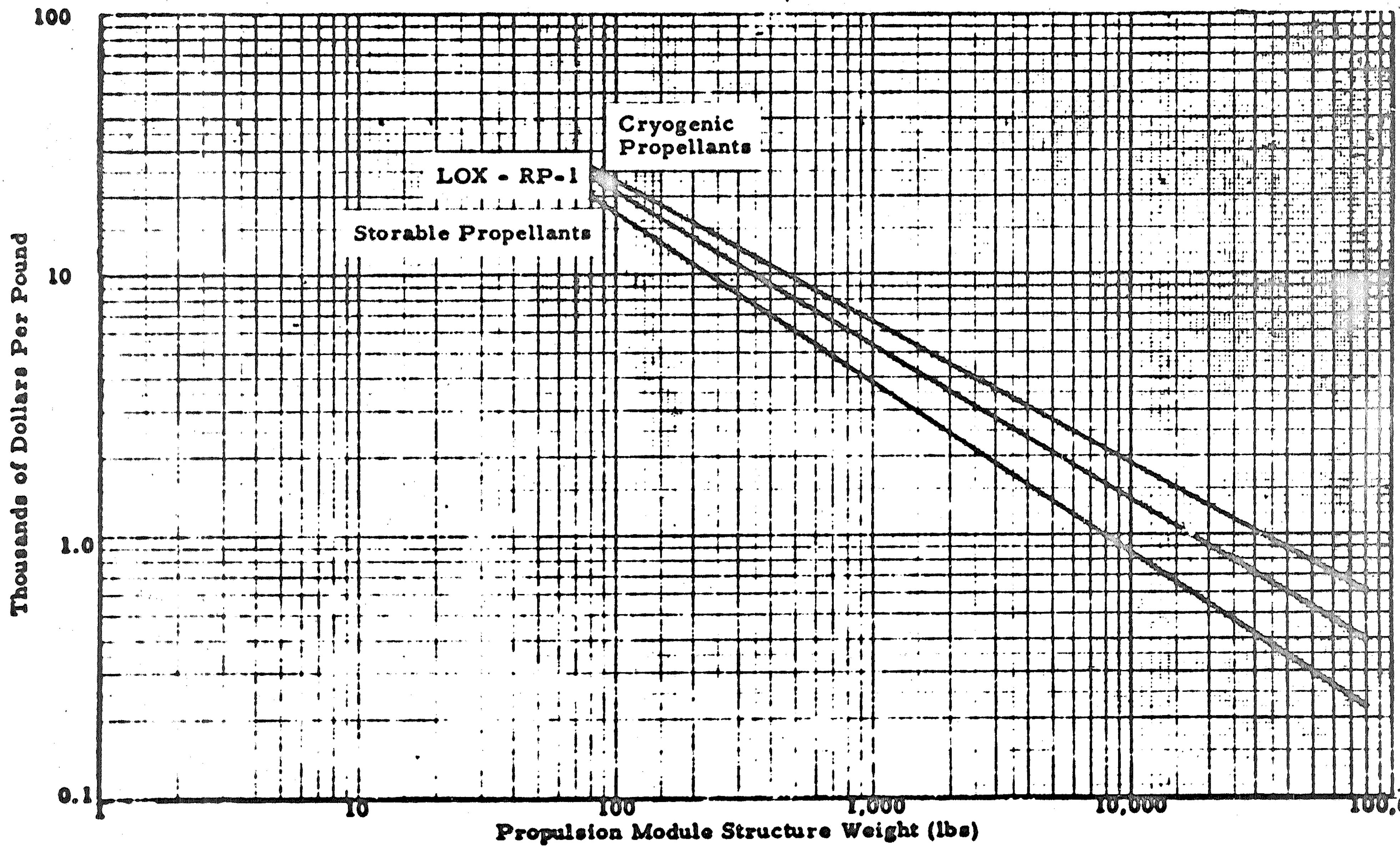


EXHIBIT 1.1B - PROPULSION MODULE STRUCTURE FIRST UNIT COST

RE-ORDER No. 66-664

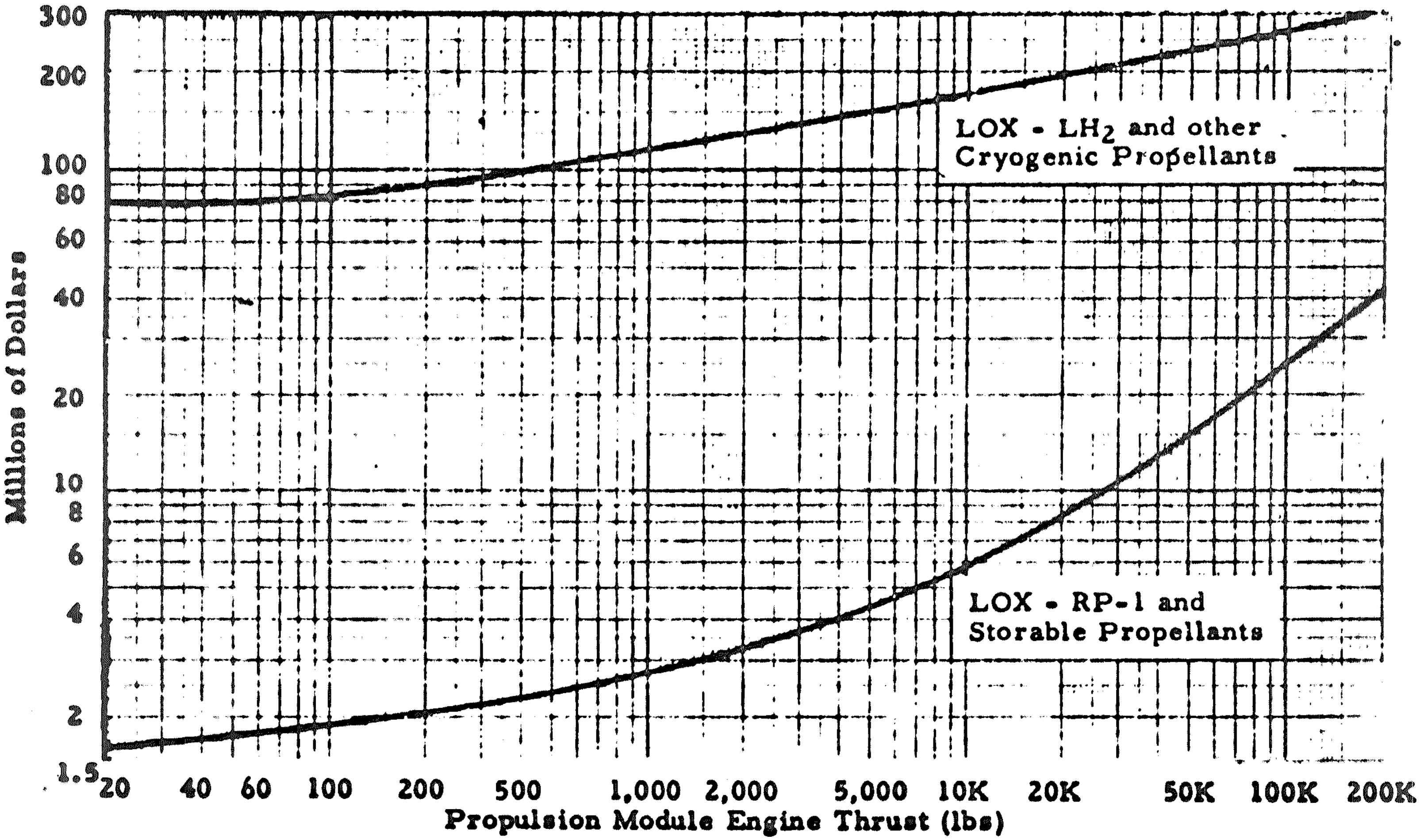


EXHIBIT 2A - PROPULSION MODULE ENGINE (LIQUID PROPELLANT) DESIGN/DEVELOPMENT COST

RE-ORDER No 66-664

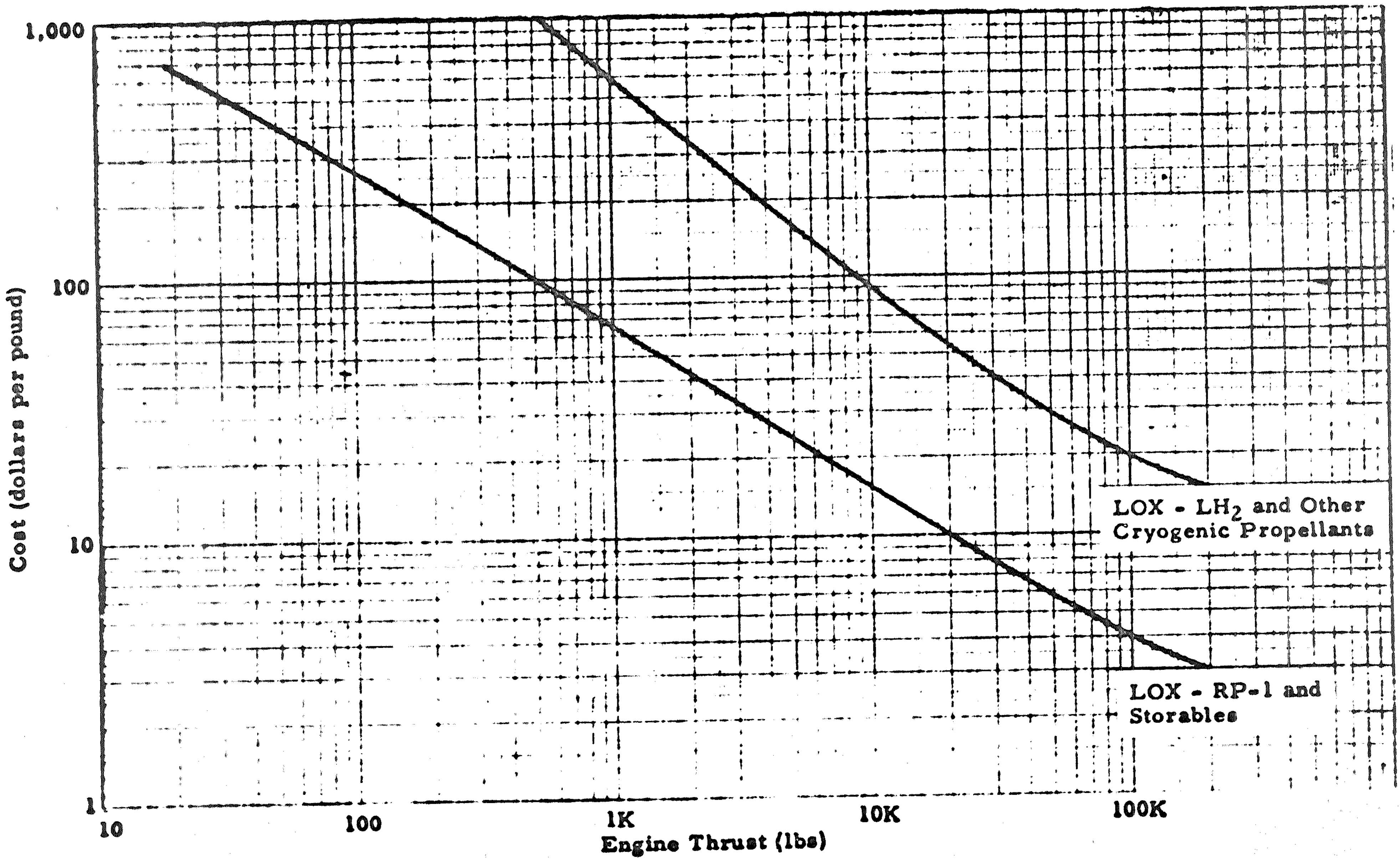


EXHIBIT 2B - PROPULSION UNIT ENGINE FIRST UNIT COST

RE-ORDER No. 66-664

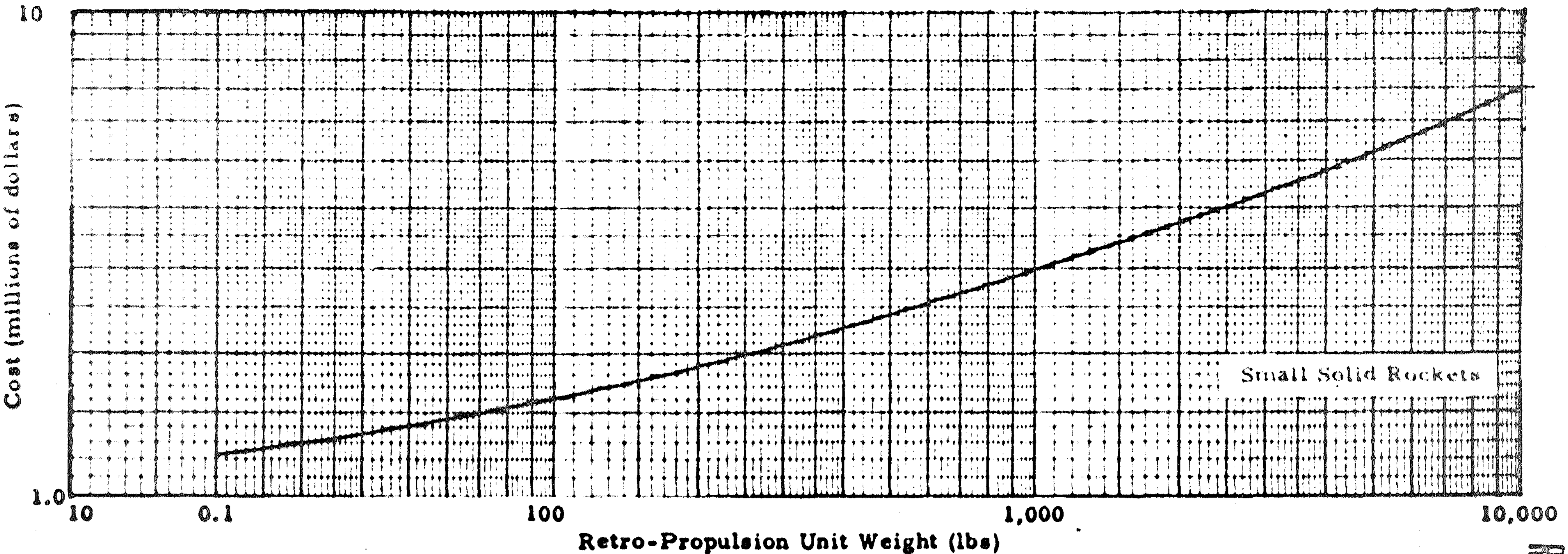


EXHIBIT 3A - RETRO-PROPULSION SYSTEMS DESIGN/DEVELOPMENT COST

RE-ORDER No. 66-664

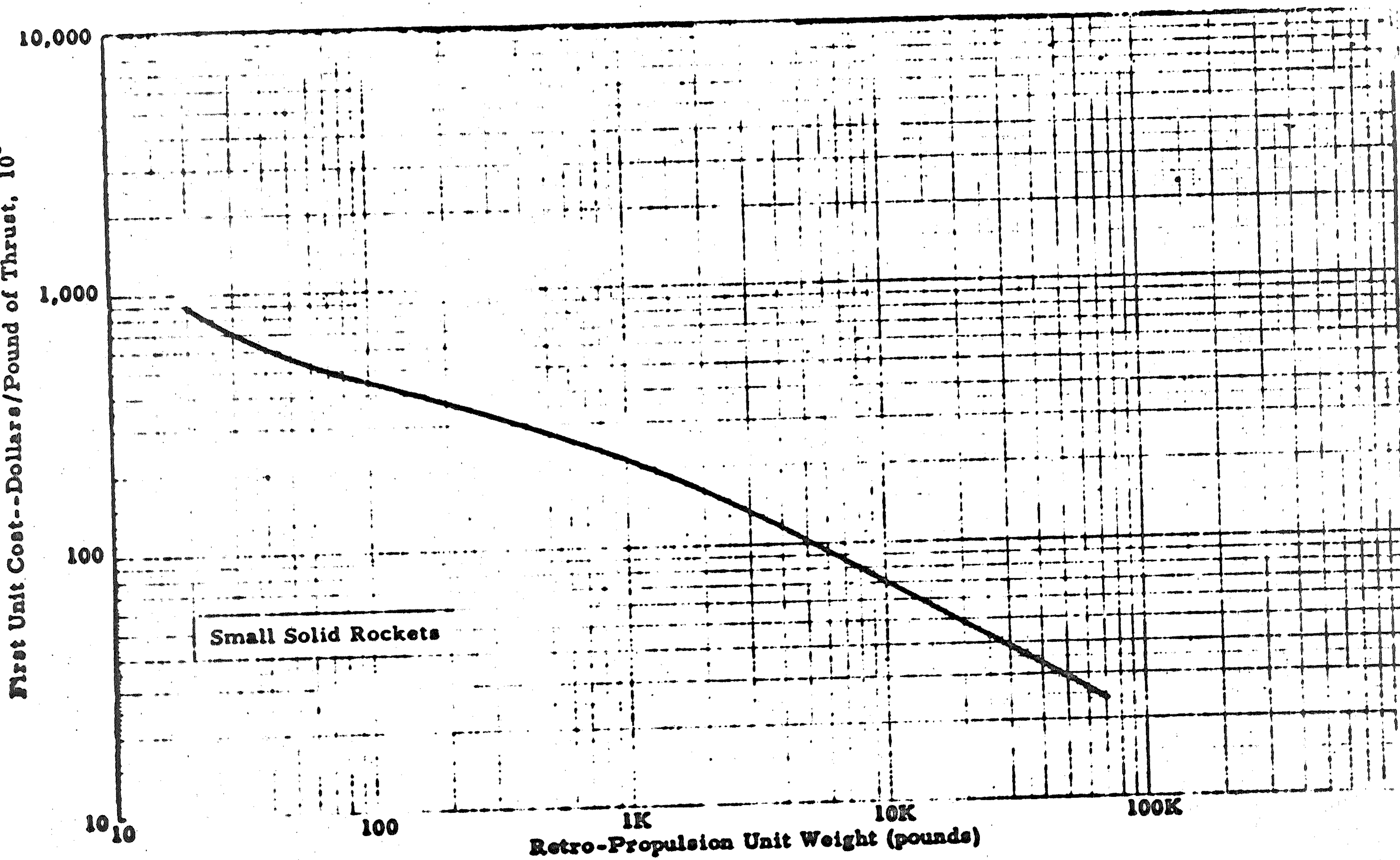


EXHIBIT 3B RETRO-PROPULSION SYSTEMS--FIRST UNIT COST

RE-ORDER No. 66-664

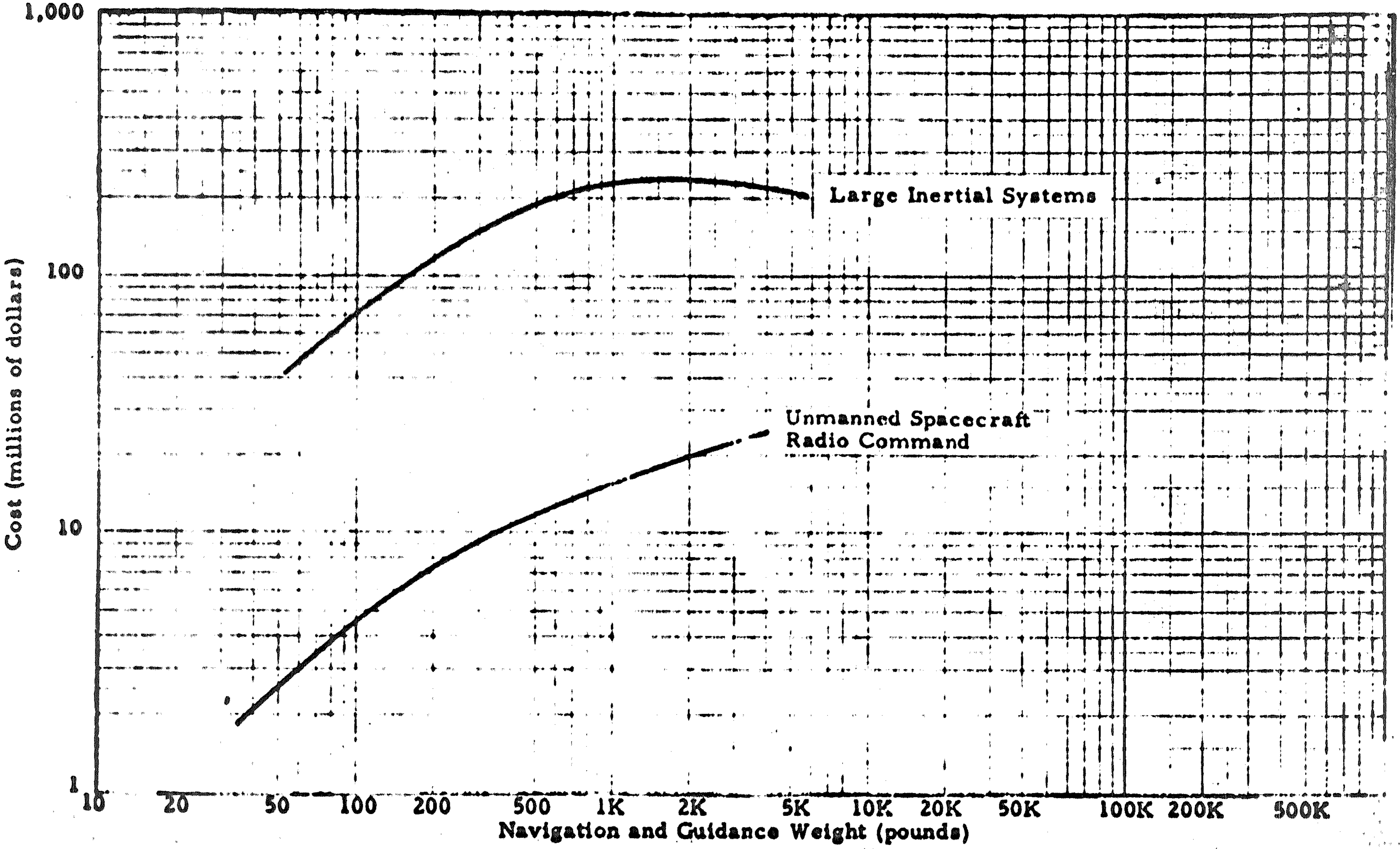


EXHIBIT 4A - NAVIGATION AND GUIDANCE DESIGN/DEVELOPMENT COST VERSUS WEIGHT

RE-ORDER No. 66-664

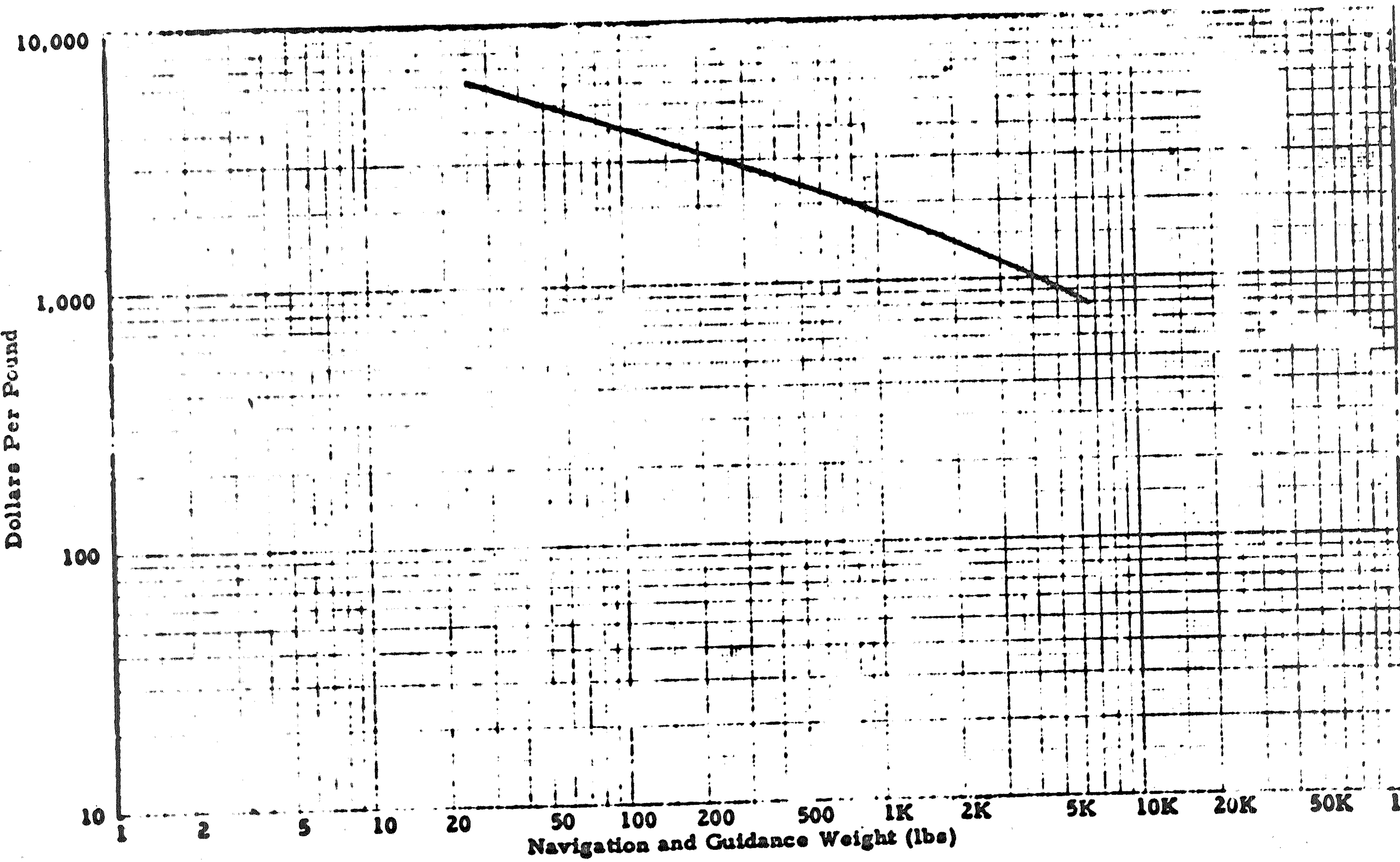


EXHIBIT 4B NAVIGATION AND GUIDANCE FIRST UNIT COST

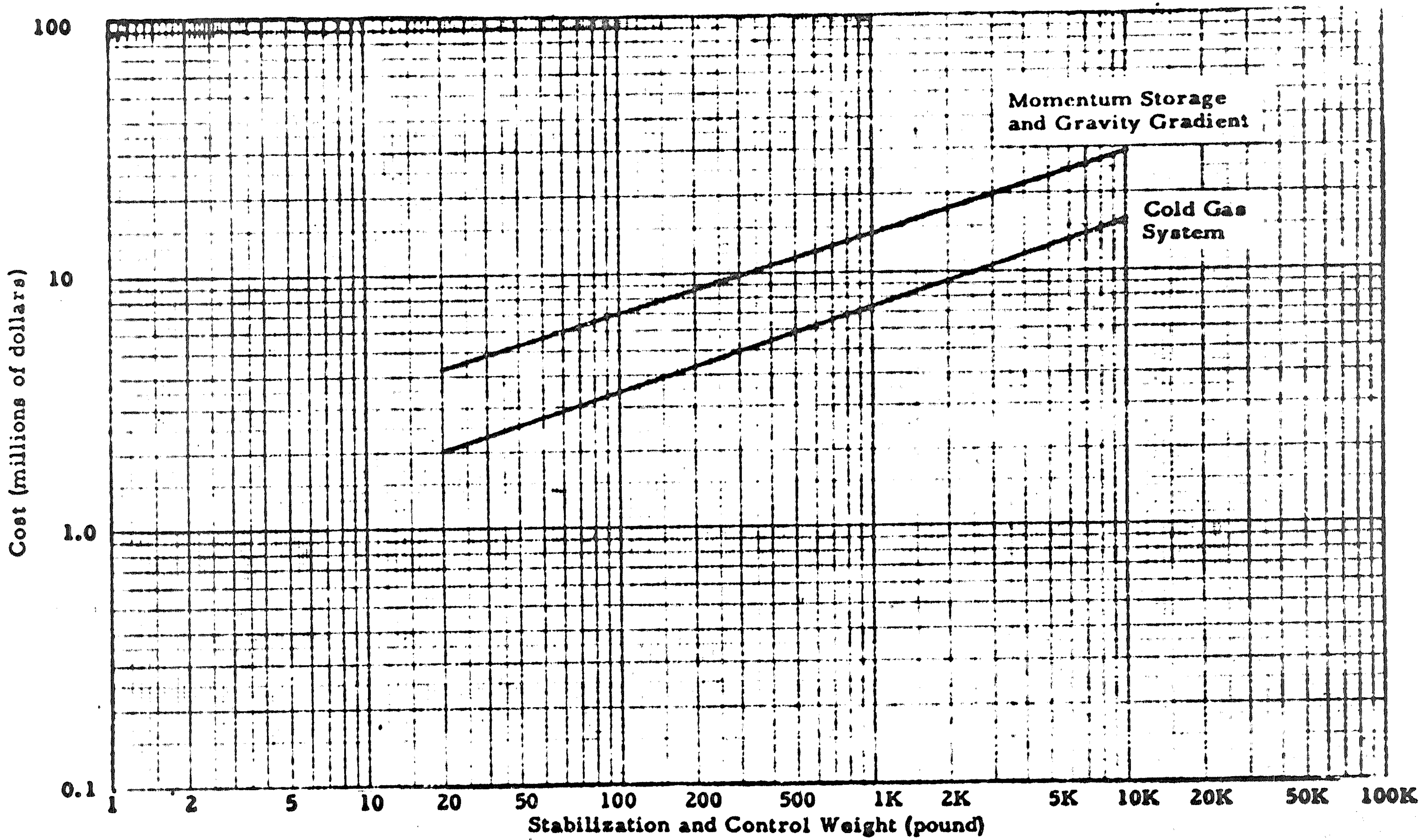


EXHIBIT 5A - STABILIZATION AND CONTROL SYSTEMS DESIGN/DEVELOPMENT COST

RE-ORDER No. 66-664

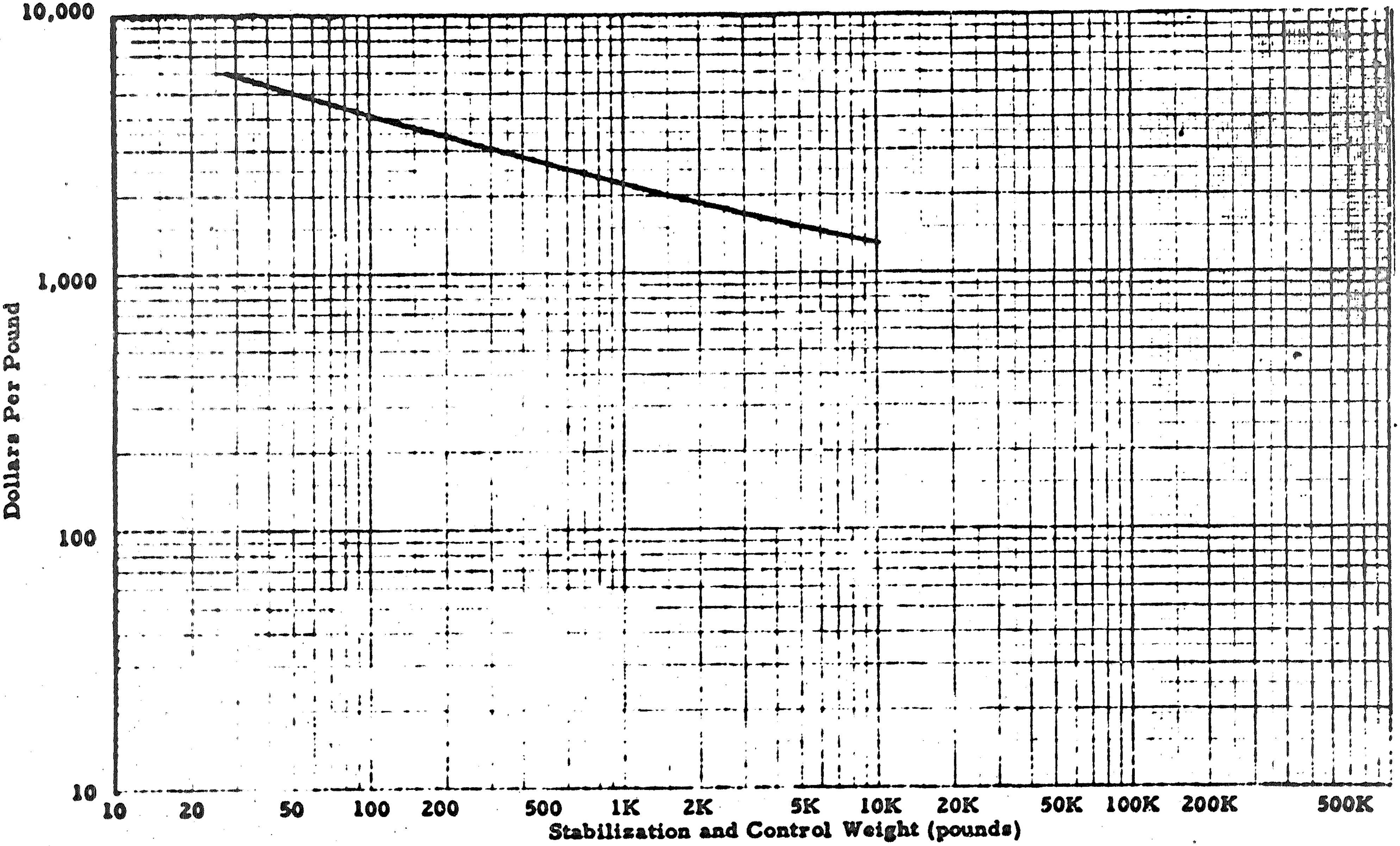


EXHIBIT 5B STABILIZATION AND CONTROL FIRST UNIT COST

RE-ORDER No. 66-664

RE-ORDER No. 66-664

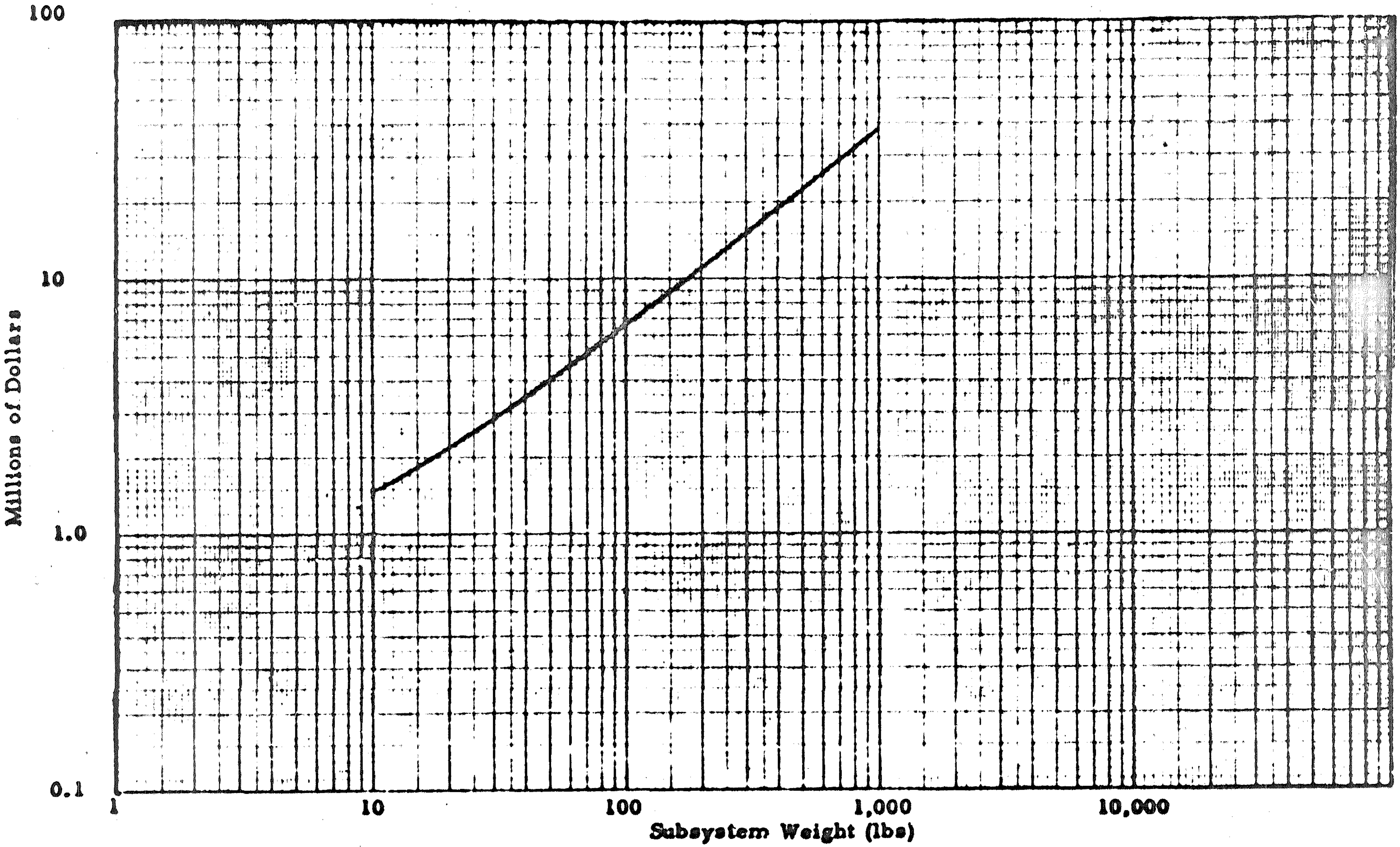


EXHIBIT 6A COMMUNICATIONS DESIGN/DEVELOPMENT COST

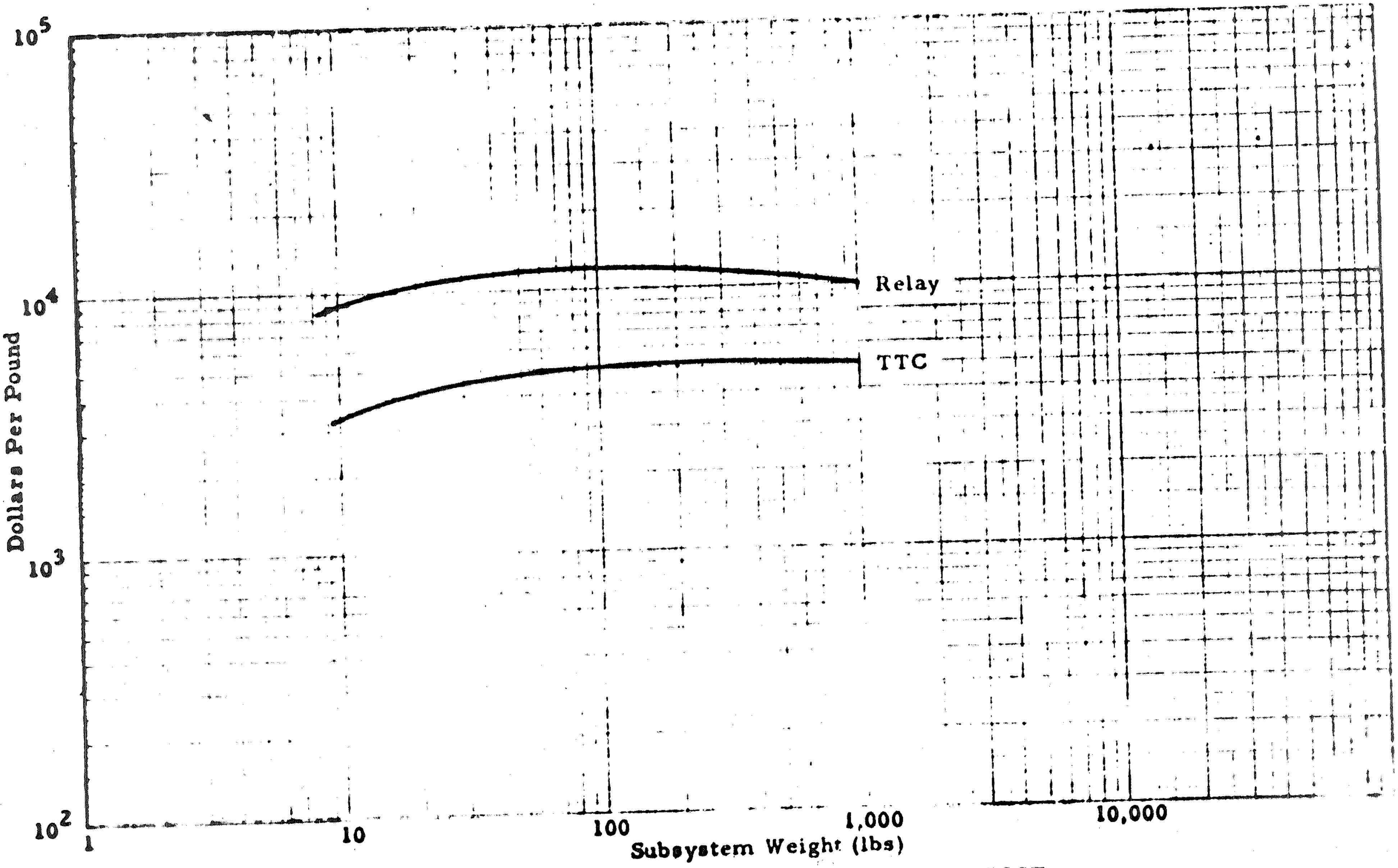


EXHIBIT 6B COMMUNICATIONS FIRST UNIT COST

RE-ORDER No. 66-664

74

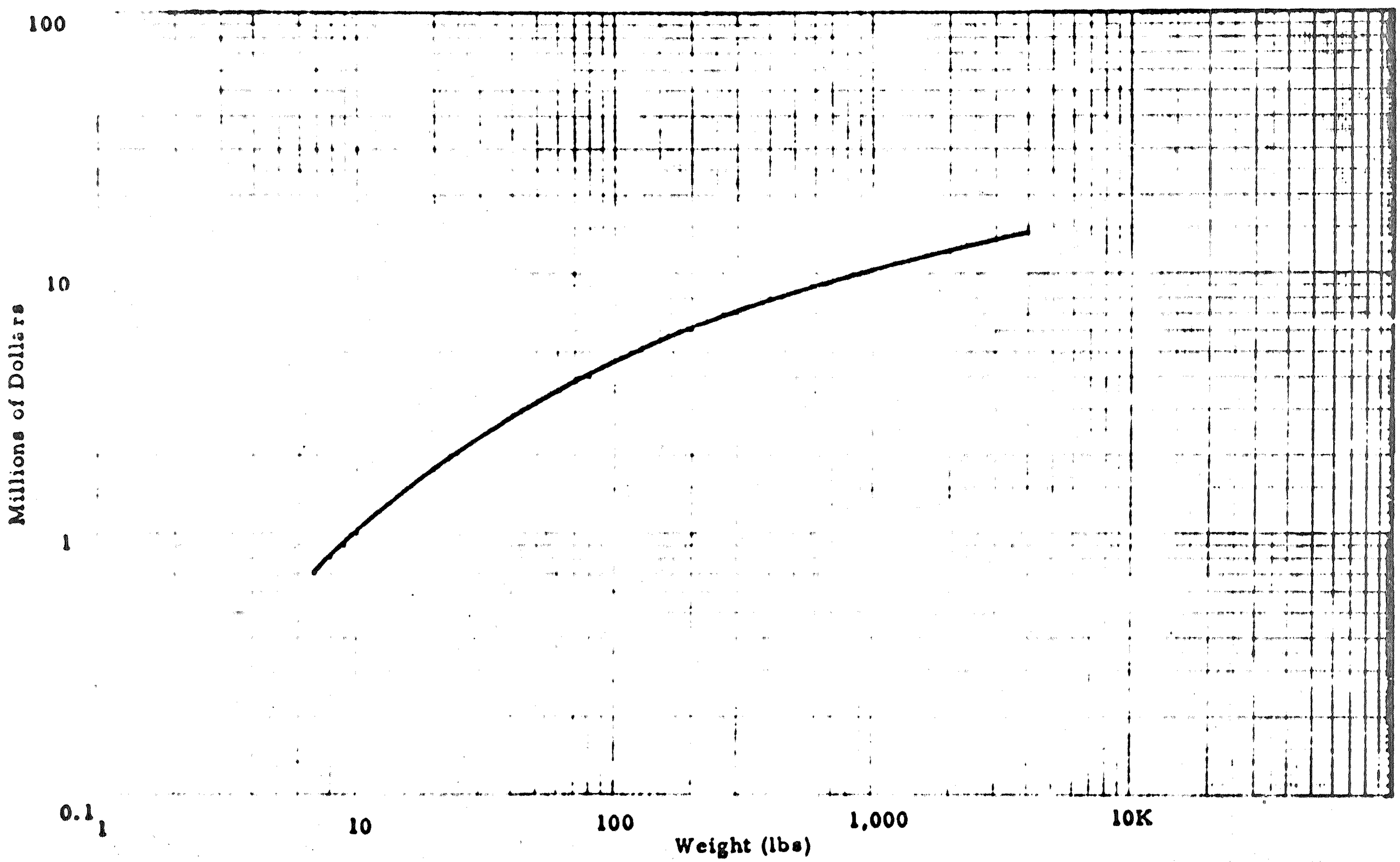


EXHIBIT 7A DATA MANAGEMENT DESIGN/DEVELOPMENT COST

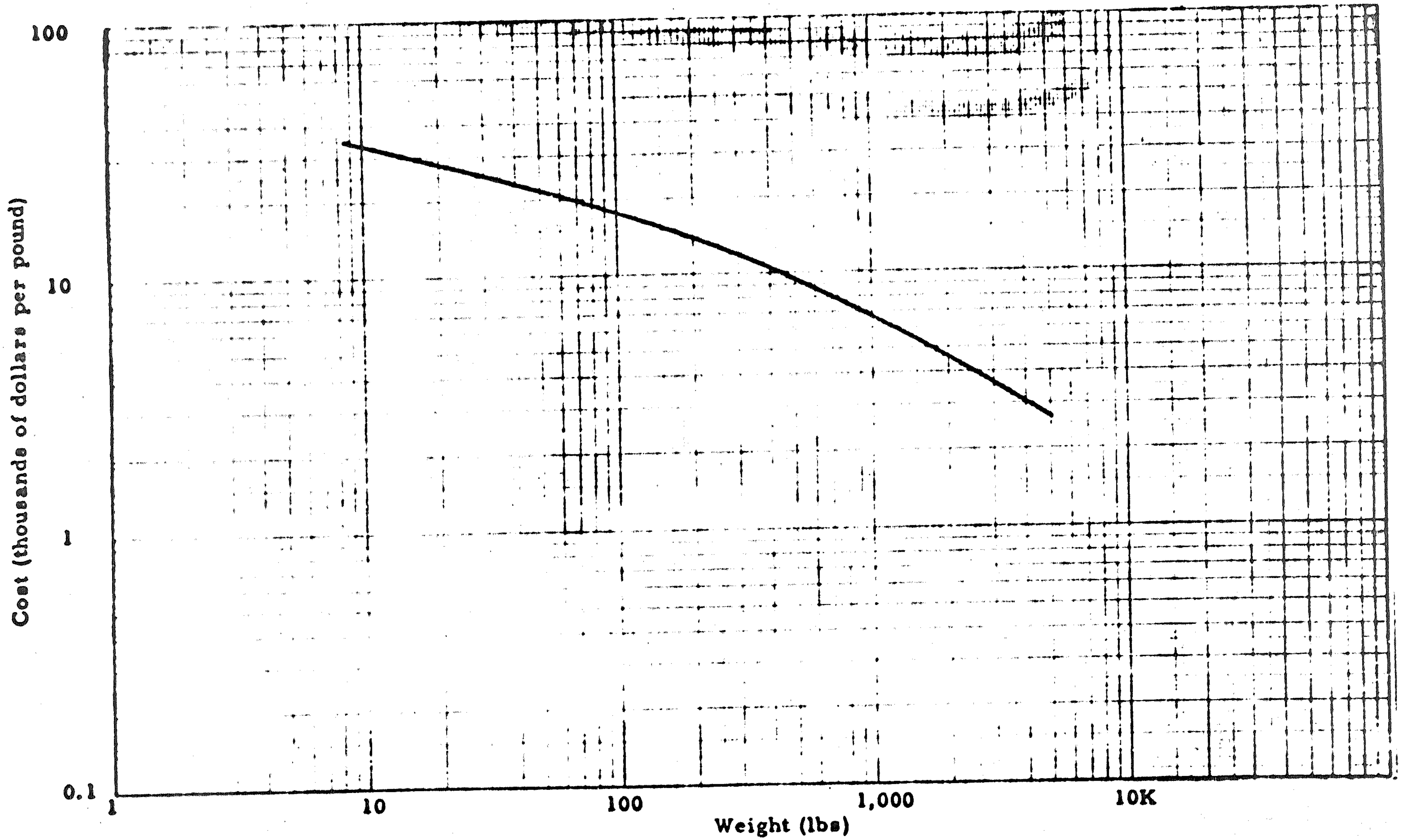


EXHIBIT 7B FIRST UNIT COST DATA MANAGEMENT

RE-ORDER No. 66-664

76

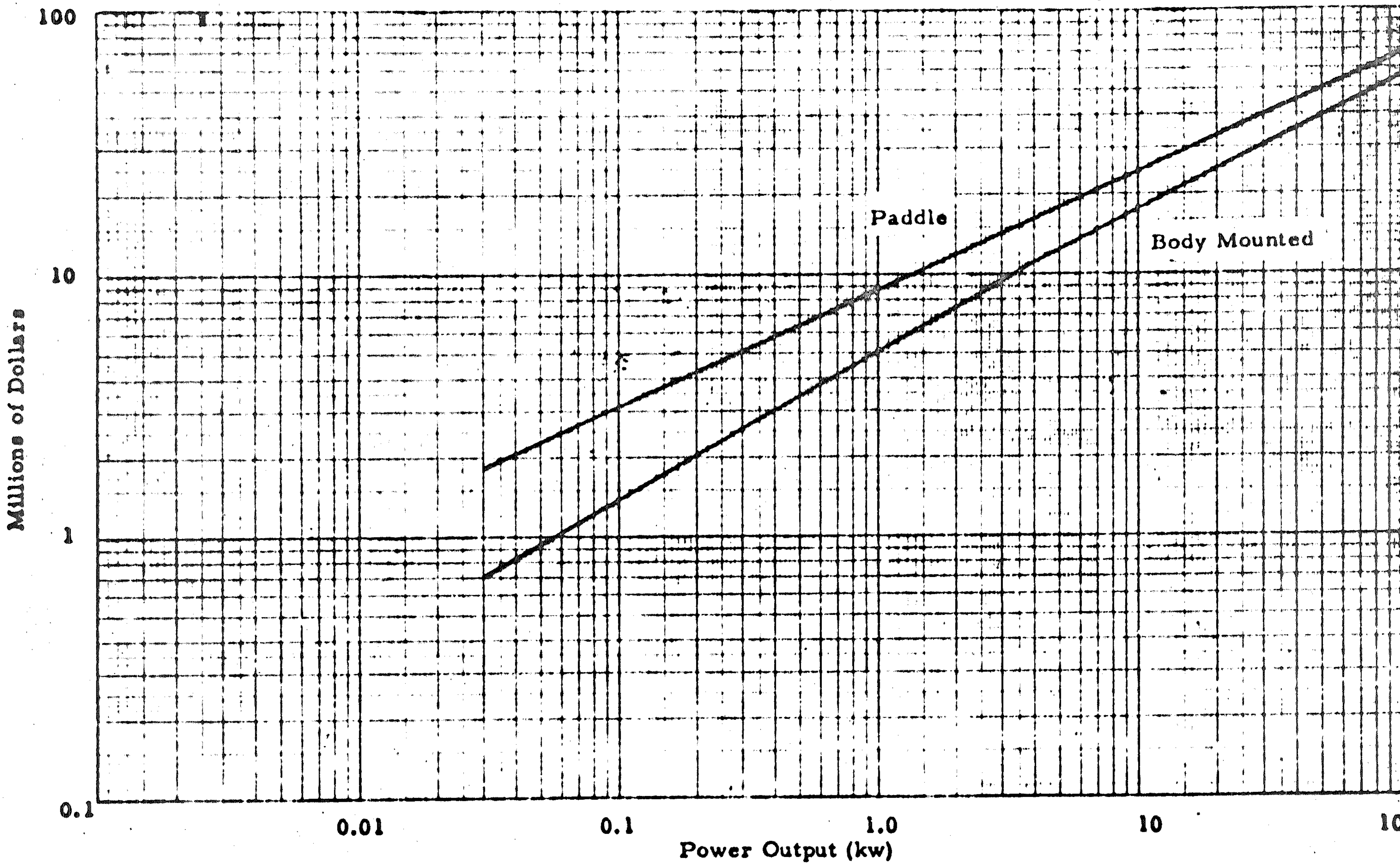


EXHIBIT 8.1A SOLAR CELL ELECTRICAL POWER SUPPLY DESIGN/DEVELOPMENT COST

RE-ORDER No. 66-664

77

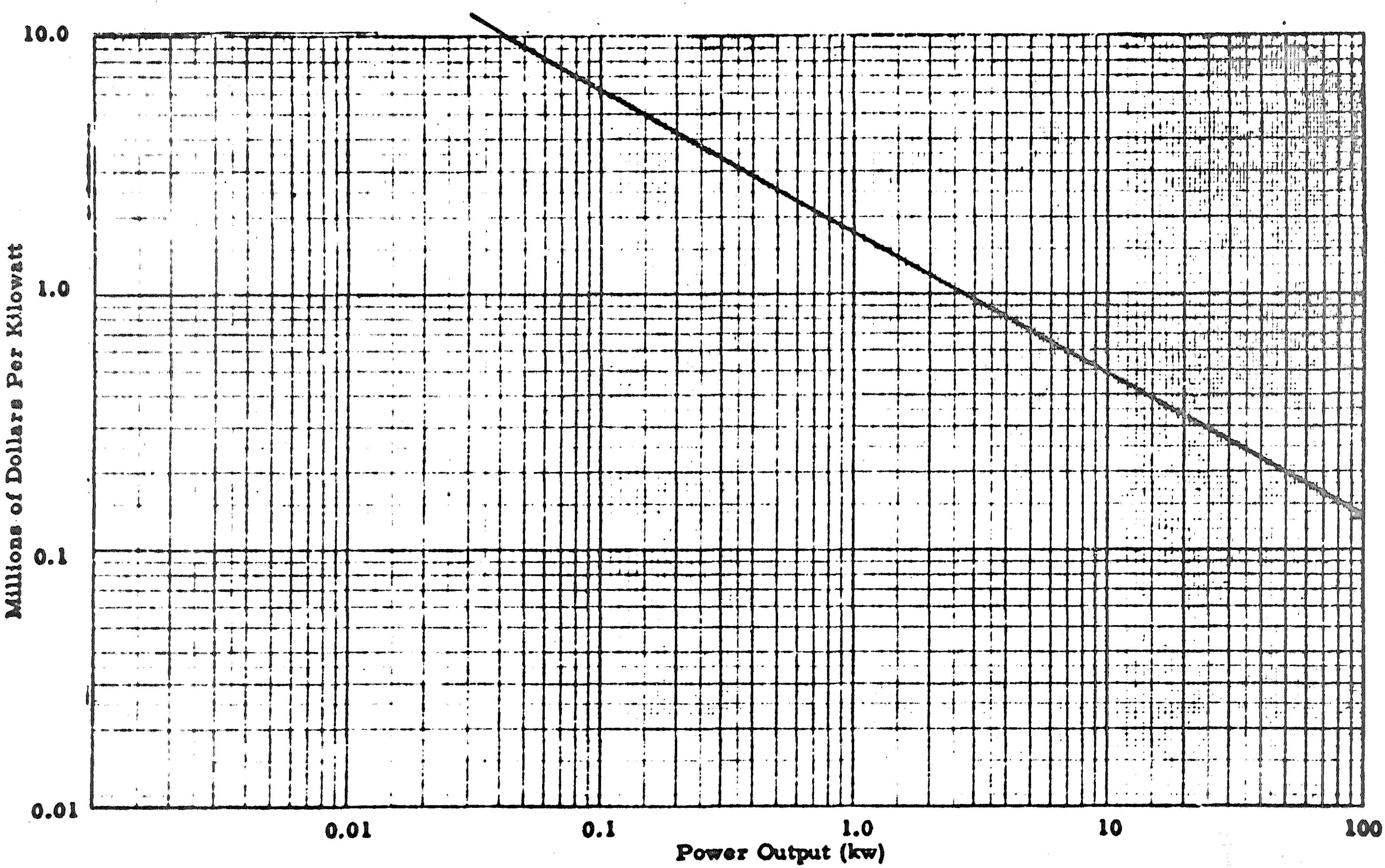


EXHIBIT 8.1B SOLAR CELL ELECTRICAL POWER SUPPLY FIRST UNIT COST

RE-ORDER No. 66-664

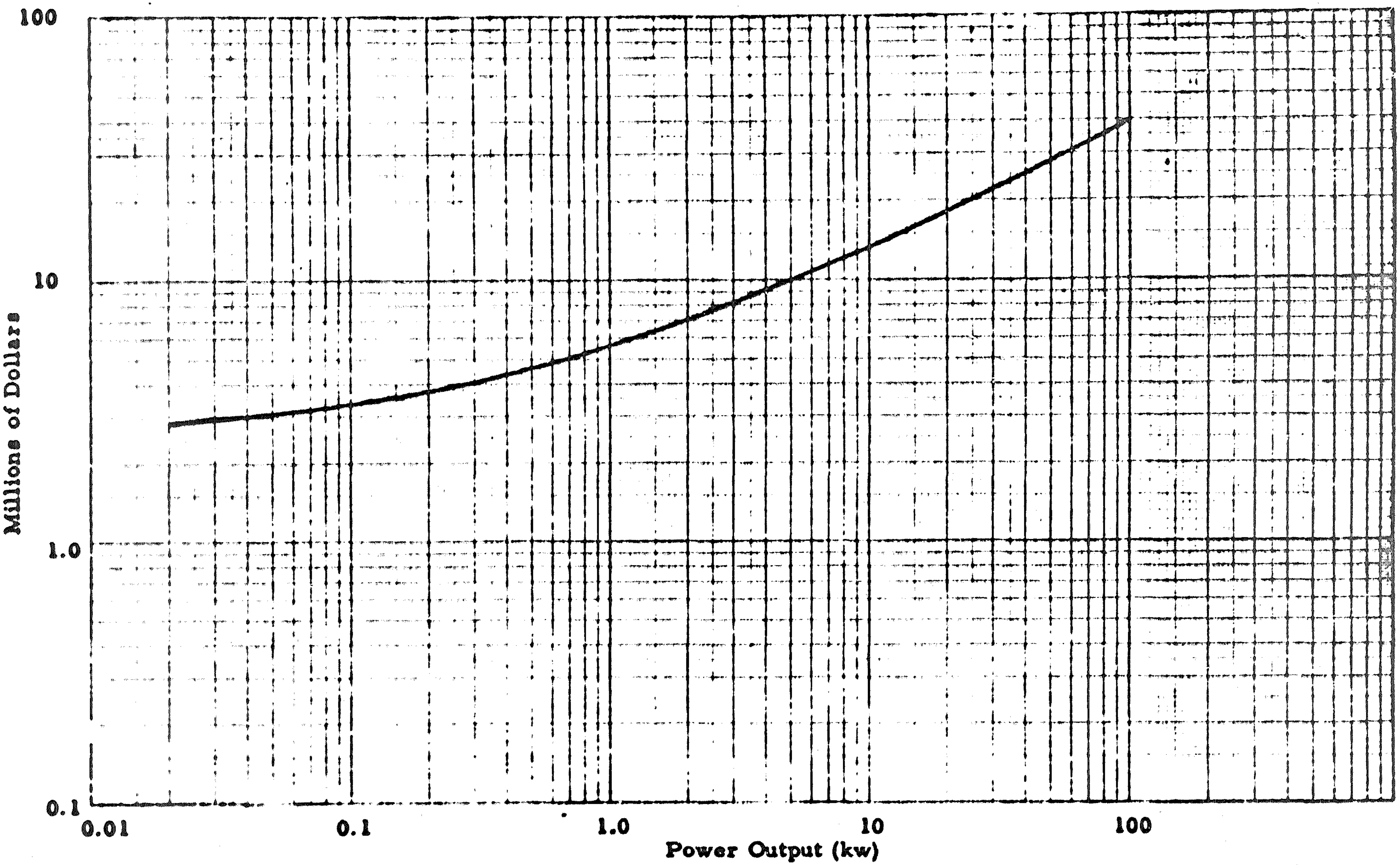


EXHIBIT 8.2A SOLAR DYNAMIC ELECTRICAL POWER SUPPLY DESIGN/DEVELOPMENT COST

RE-ORDER No. 66-664

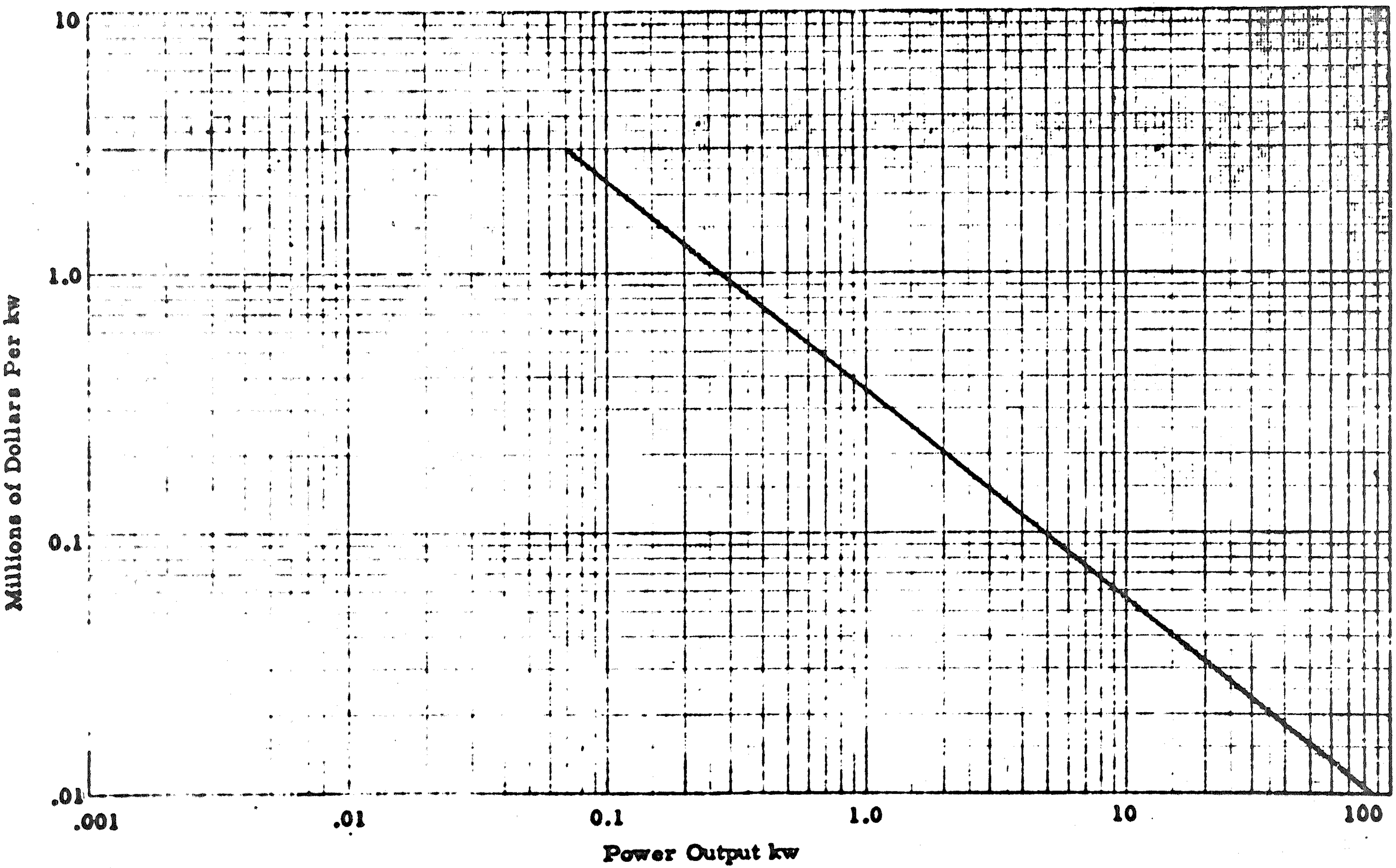


EXHIBIT 8.2B SOLAR DYNAMIC ELECTRICAL POWER SUPPLY FIRST UNIT COST

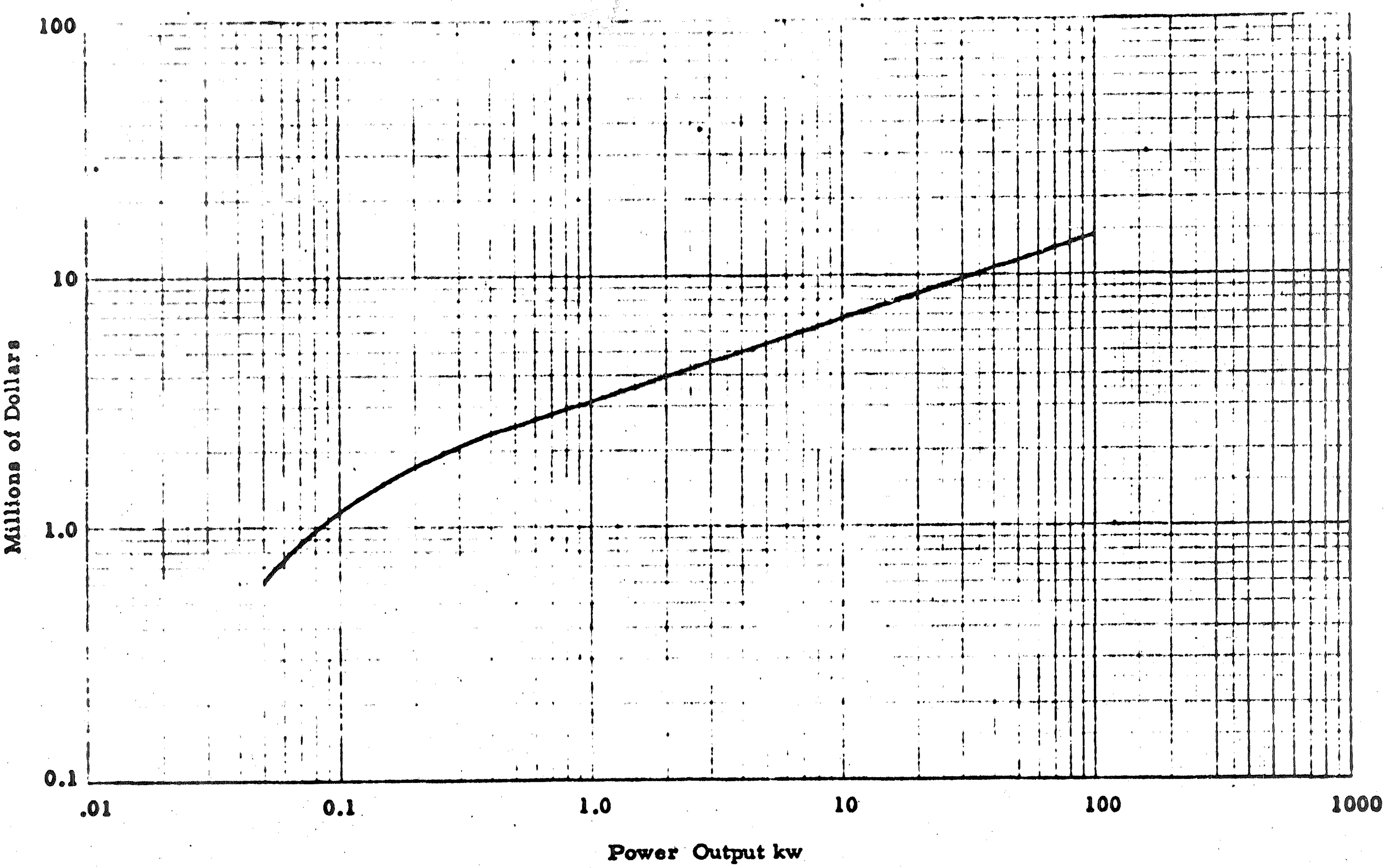


EXHIBIT 8.3A FUEL CELL ELECTRICAL POWER SUPPLY DESIGN/DEVELOPMENT COST

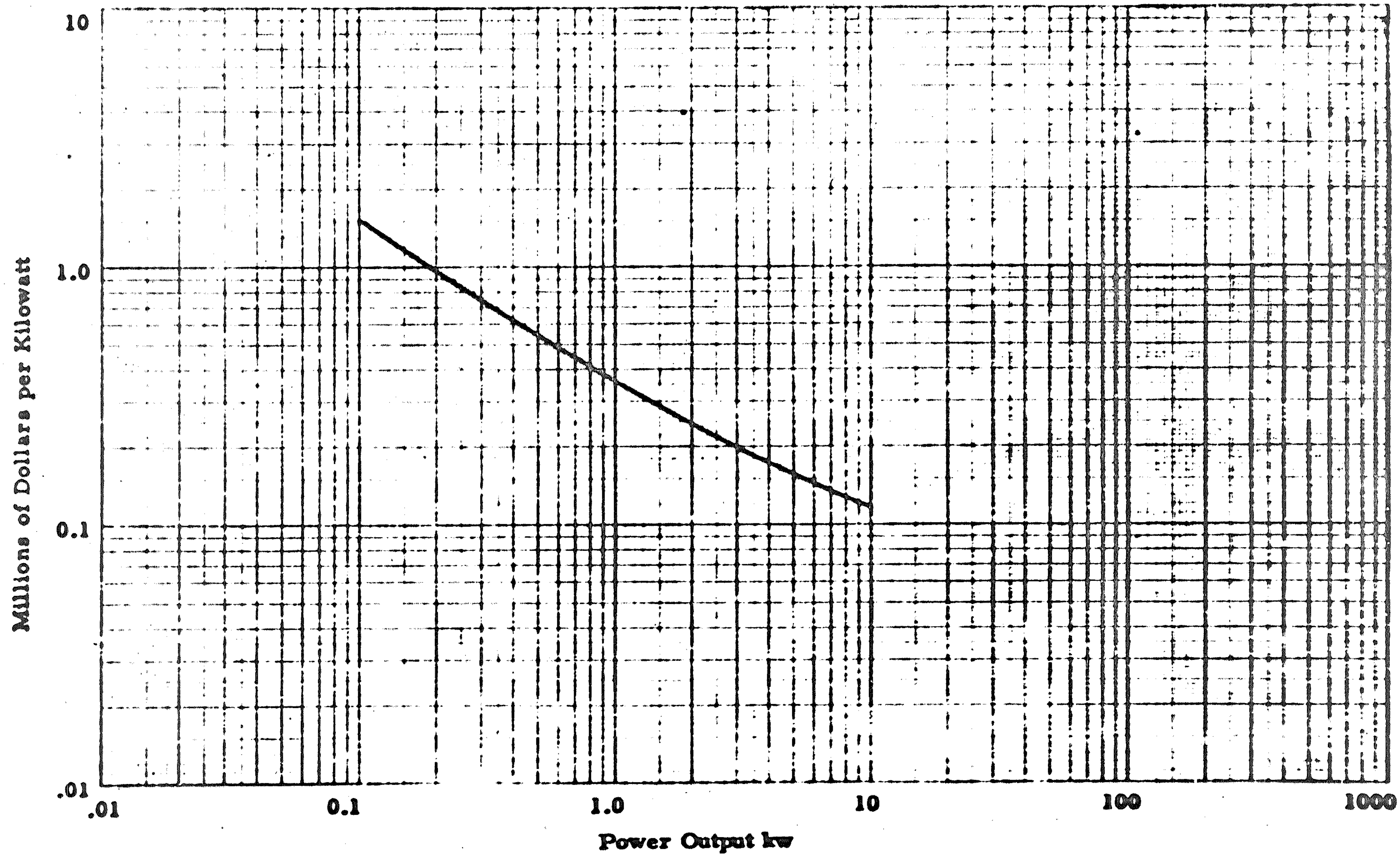


EXHIBIT 8.3B FUEL CELL ELECTRICAL POWER SUPPLY FIRST UNIT COST

RE-ORDER No. 66-664

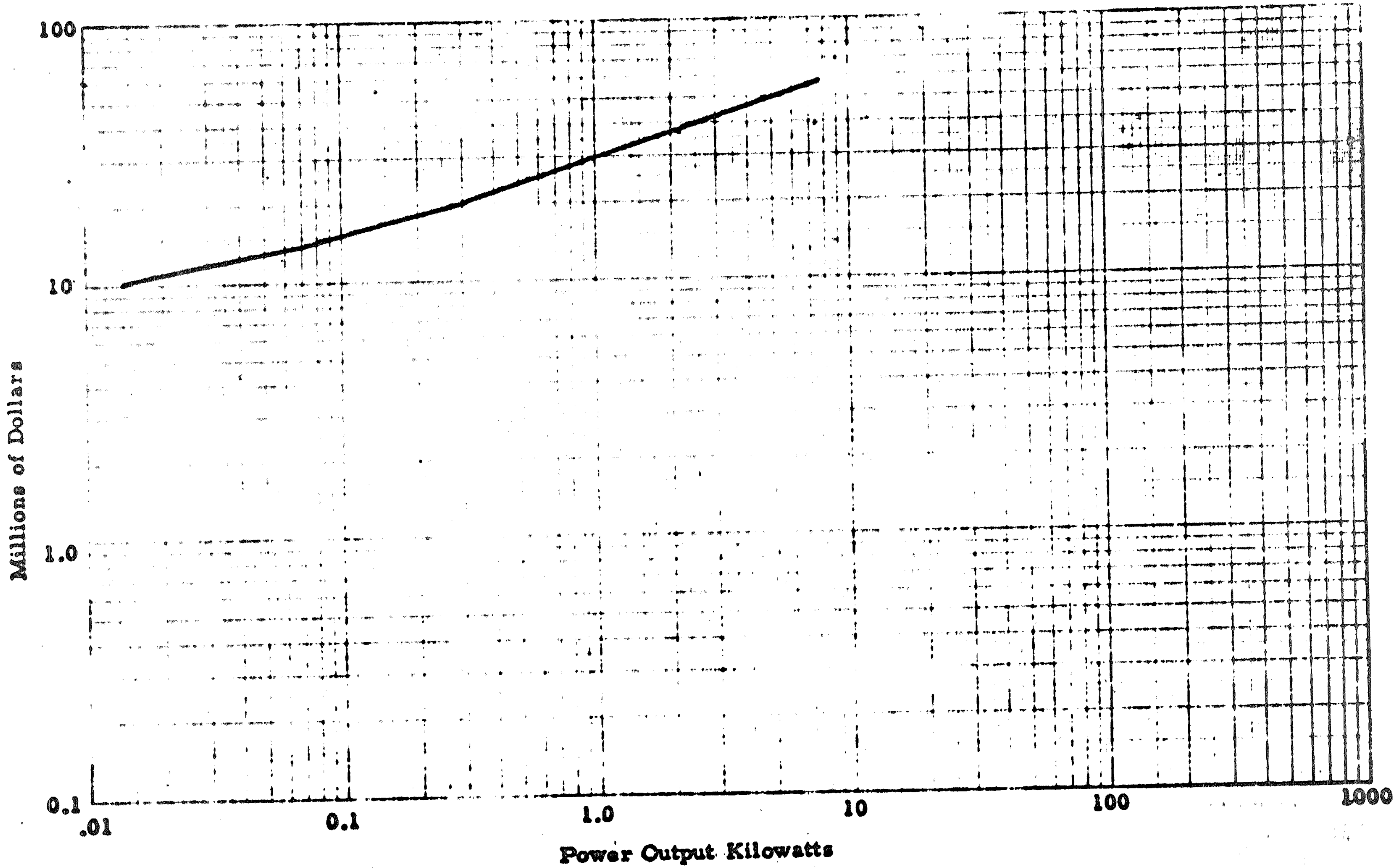


EXHIBIT 8.4A ISOTOPE ELECTRICAL POWER SUPPLY DESIGN/DEVELOPMENT COST

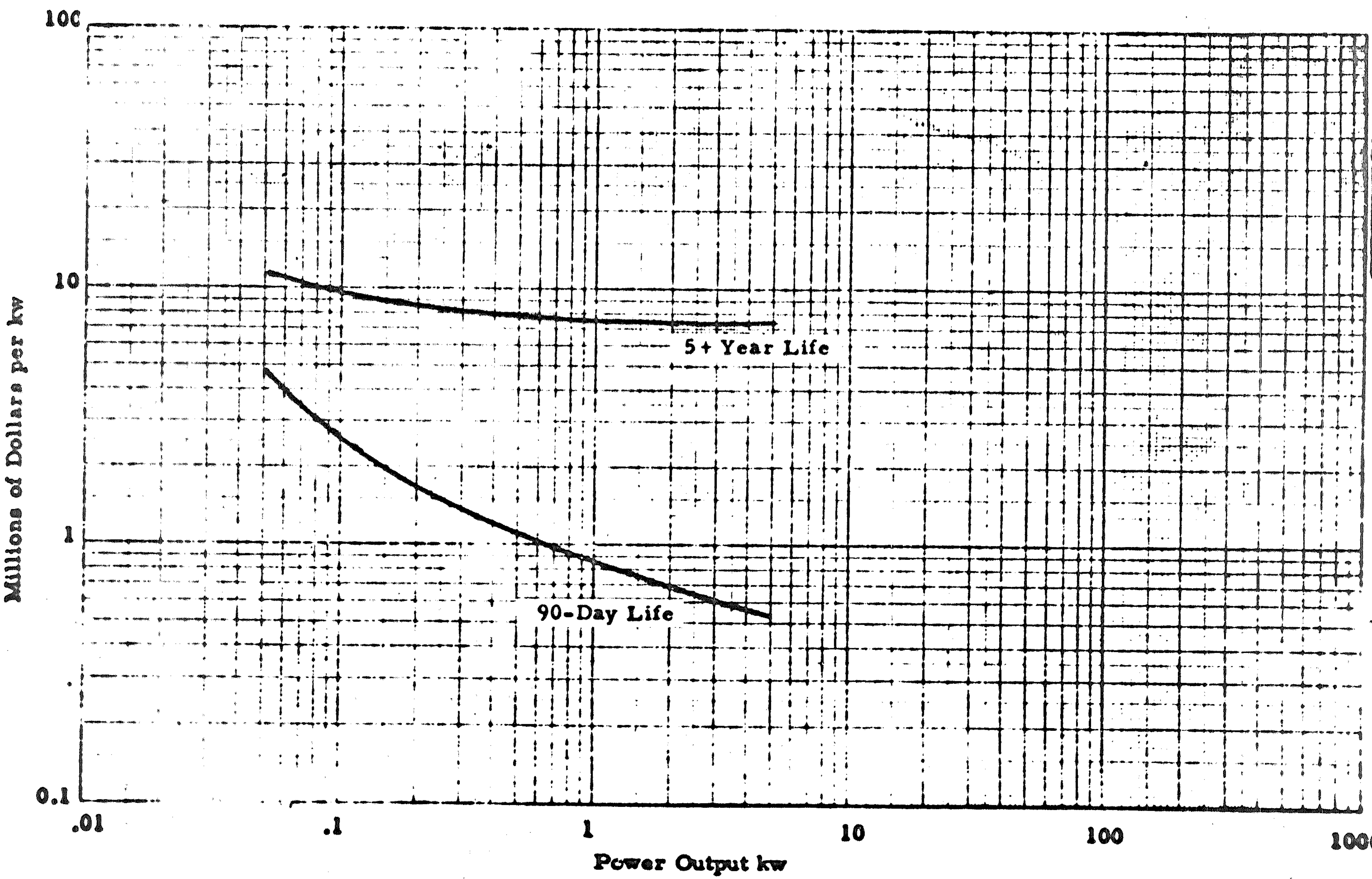
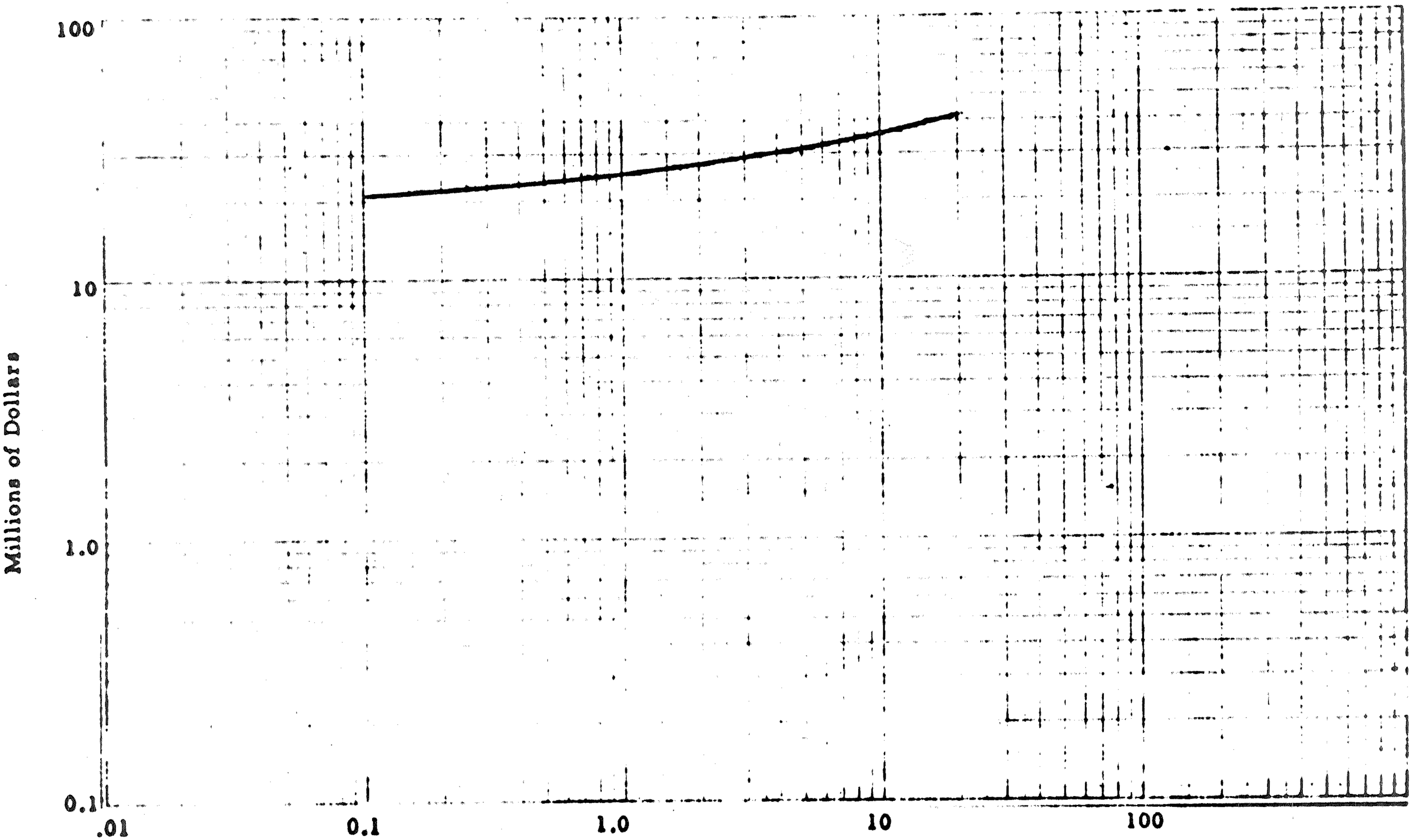


EXHIBIT 8.4B ISOTOPE ELECTRICAL POWER SUPPLY FIRST UNIT COST

RE-ORDER No. 66-664

RE-ORDER No. 66-664



Power Output Kilowatts

EXHIBIT 8.5A SNAP NUCLEAR REACTOR ELECTRICAL POWER SUPPLY DESIGN/DEVELOPMENT COST

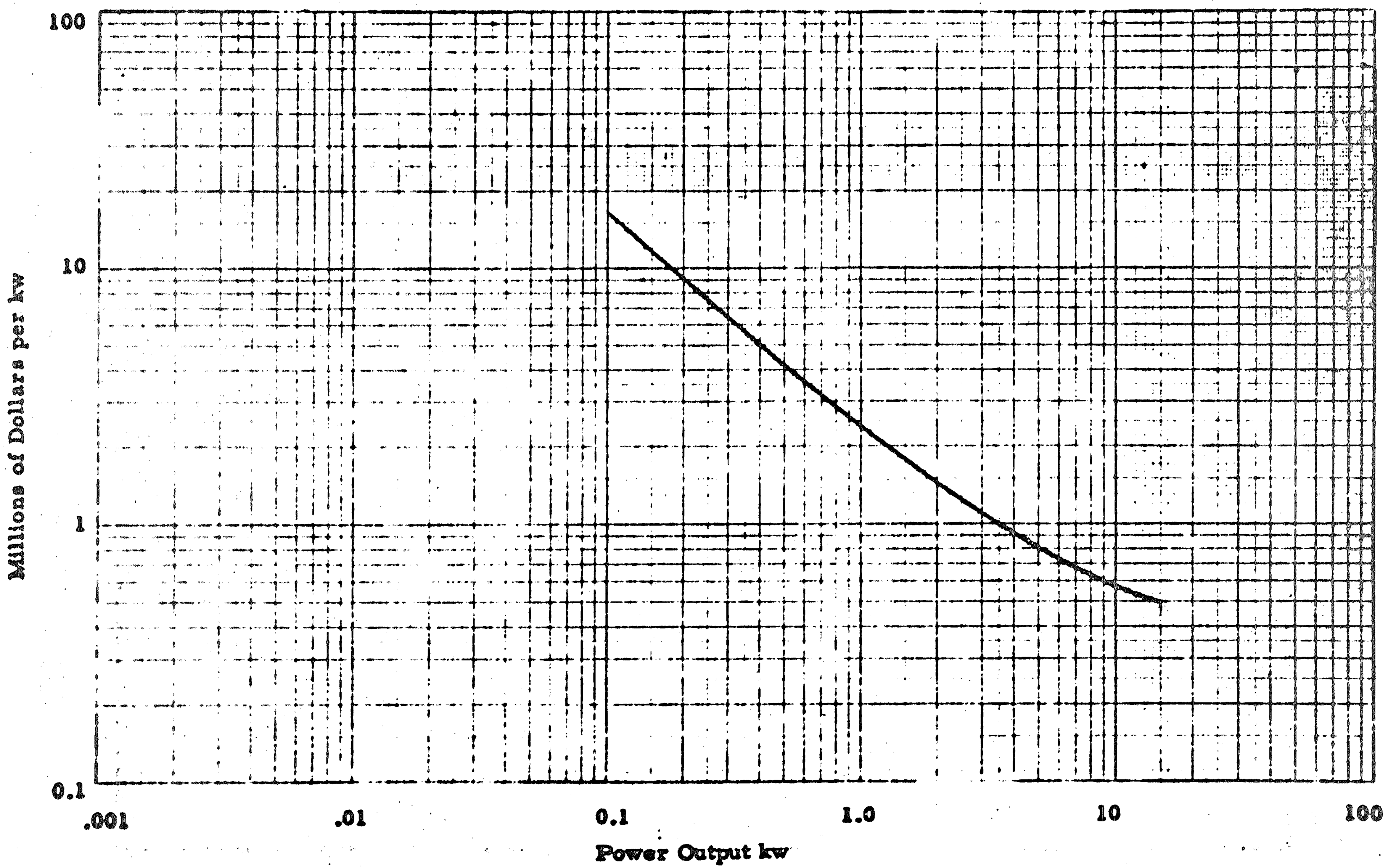
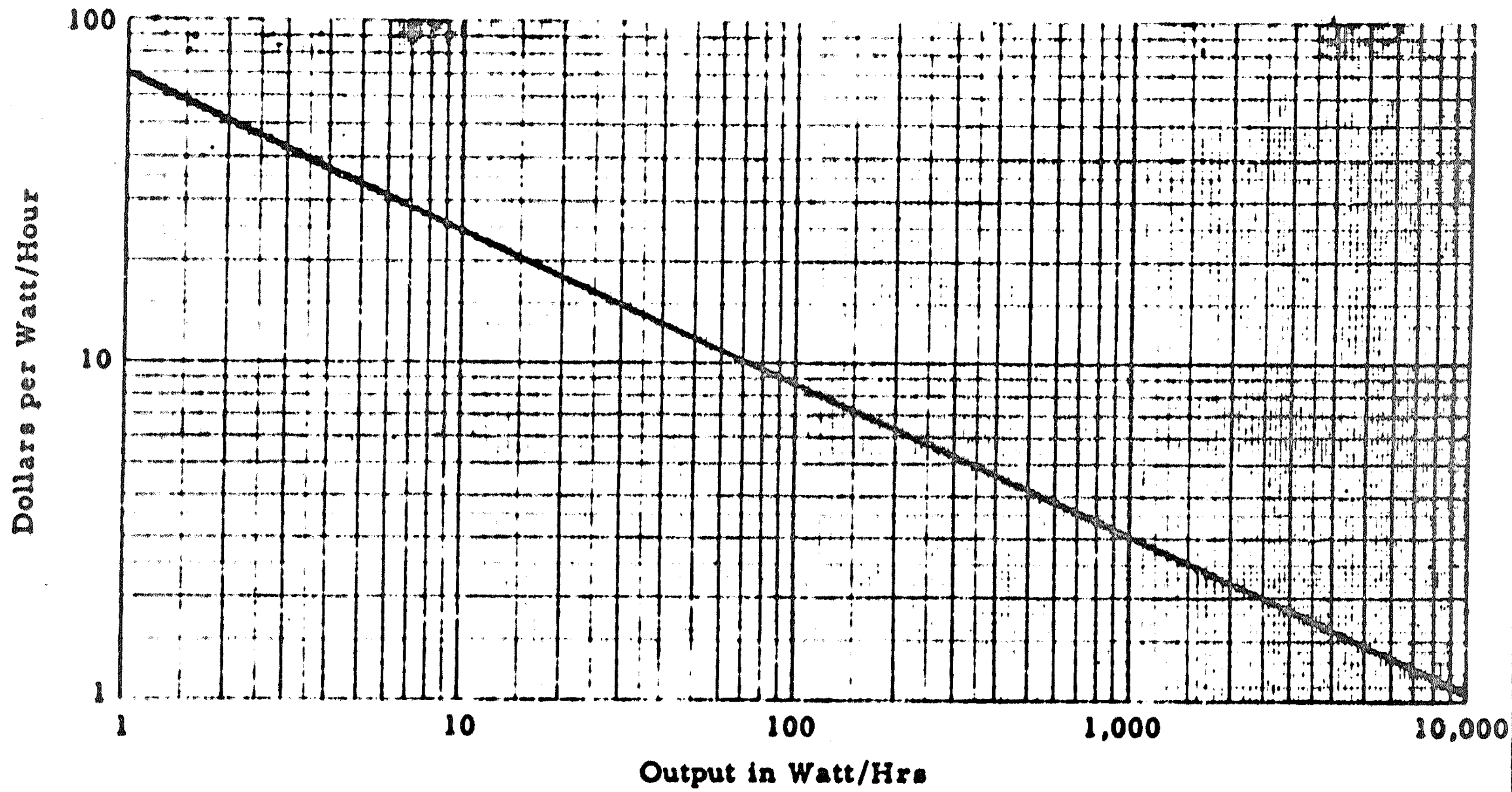


EXHIBIT 8.5B SNAP NUCLEAR REACTOR ELECTRICAL POWER SUPPLY FIRST UNIT COST

RE-ORDER No. 66-664

86



Note: Design and Development cost = 0
Learning curve = 100%

EXHIBIT 8.6A - BATTERY FIRST UNIT COST

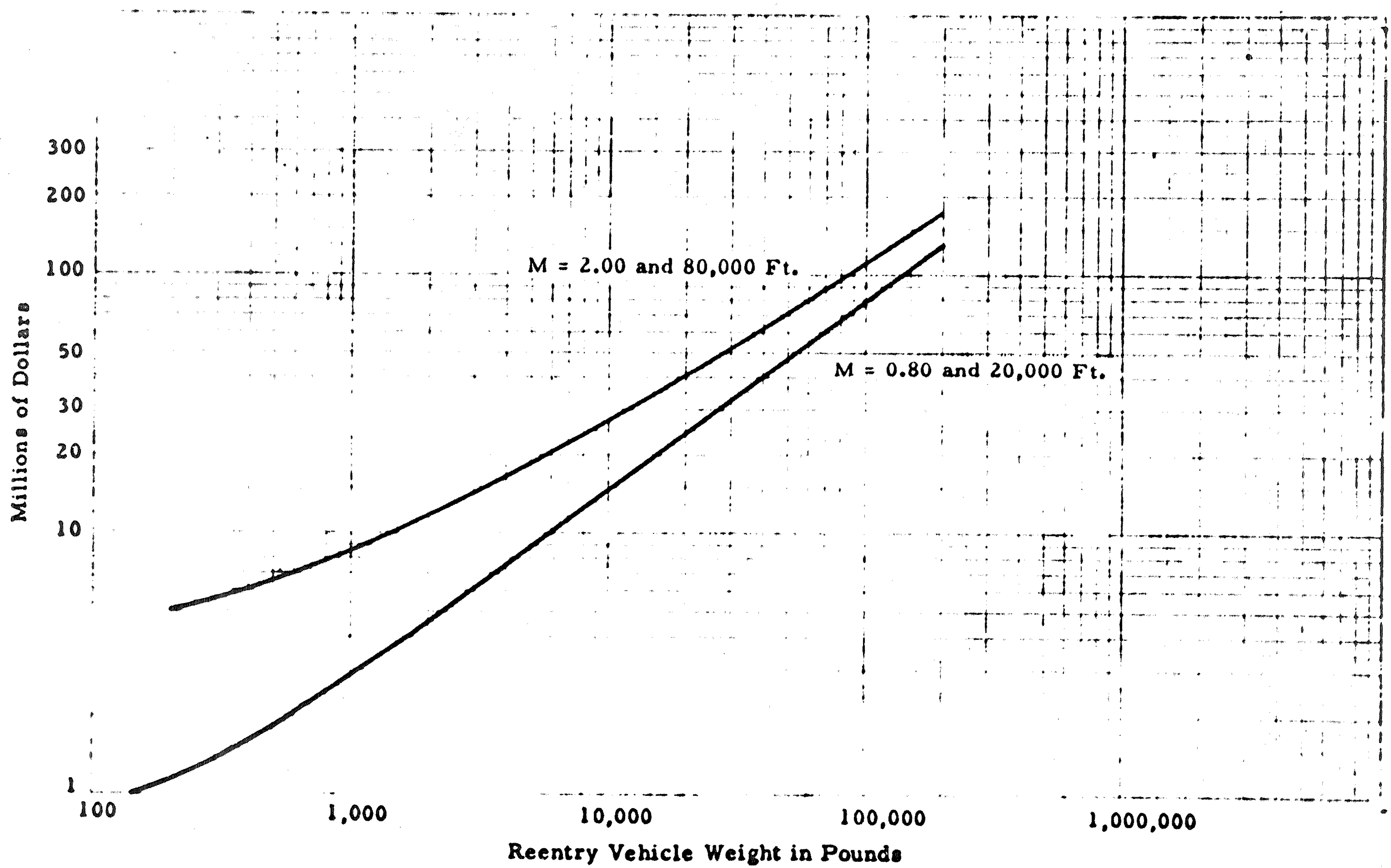


EXHIBIT 9A PARACHUTE DESCENT SYSTEMS DESIGN/DEVELOPMENT COST

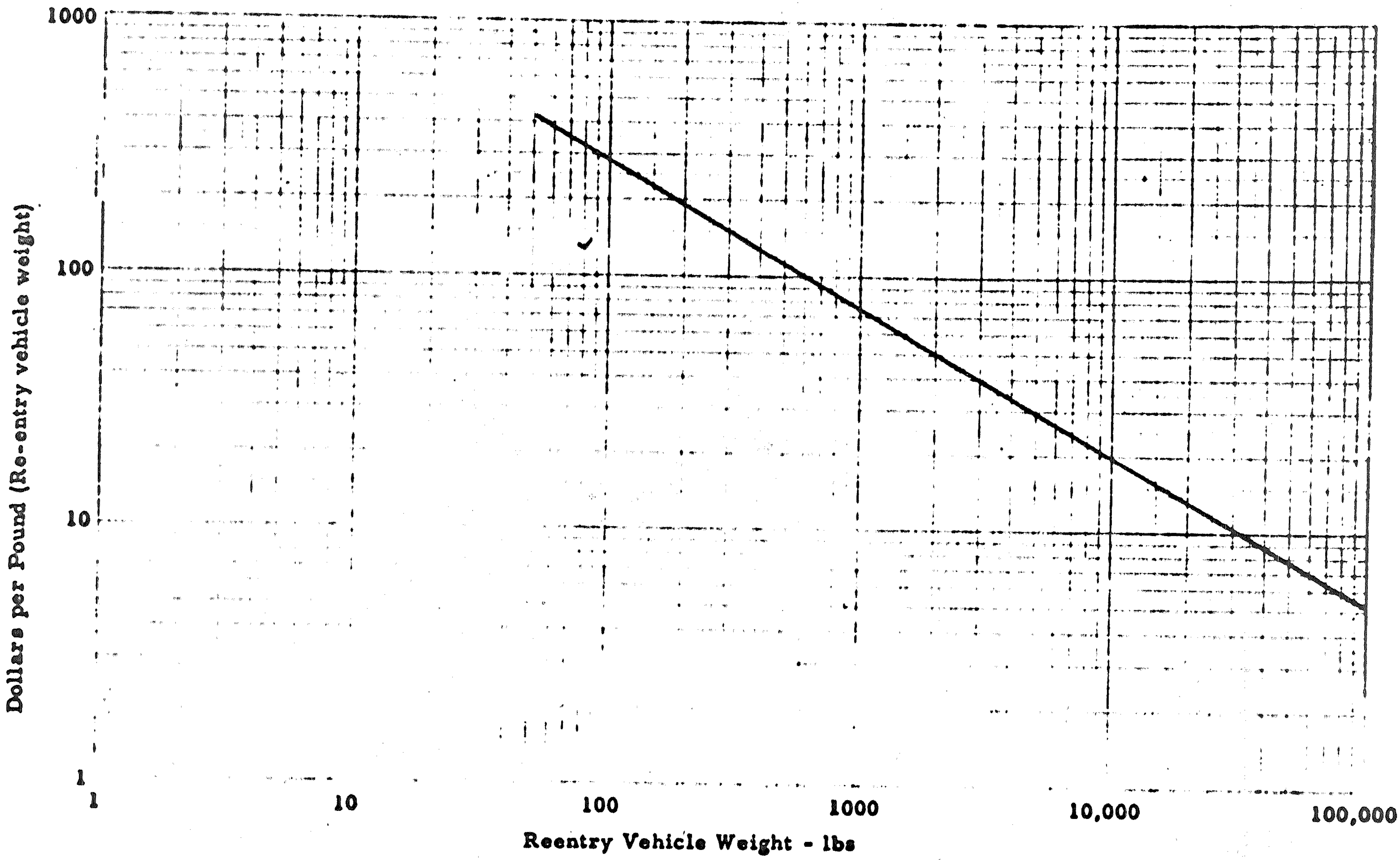


EXHIBIT 9B PARACHUTE DESCENT SYSTEMS FIRST UNIT COST

RE-ORDER No. 66-664

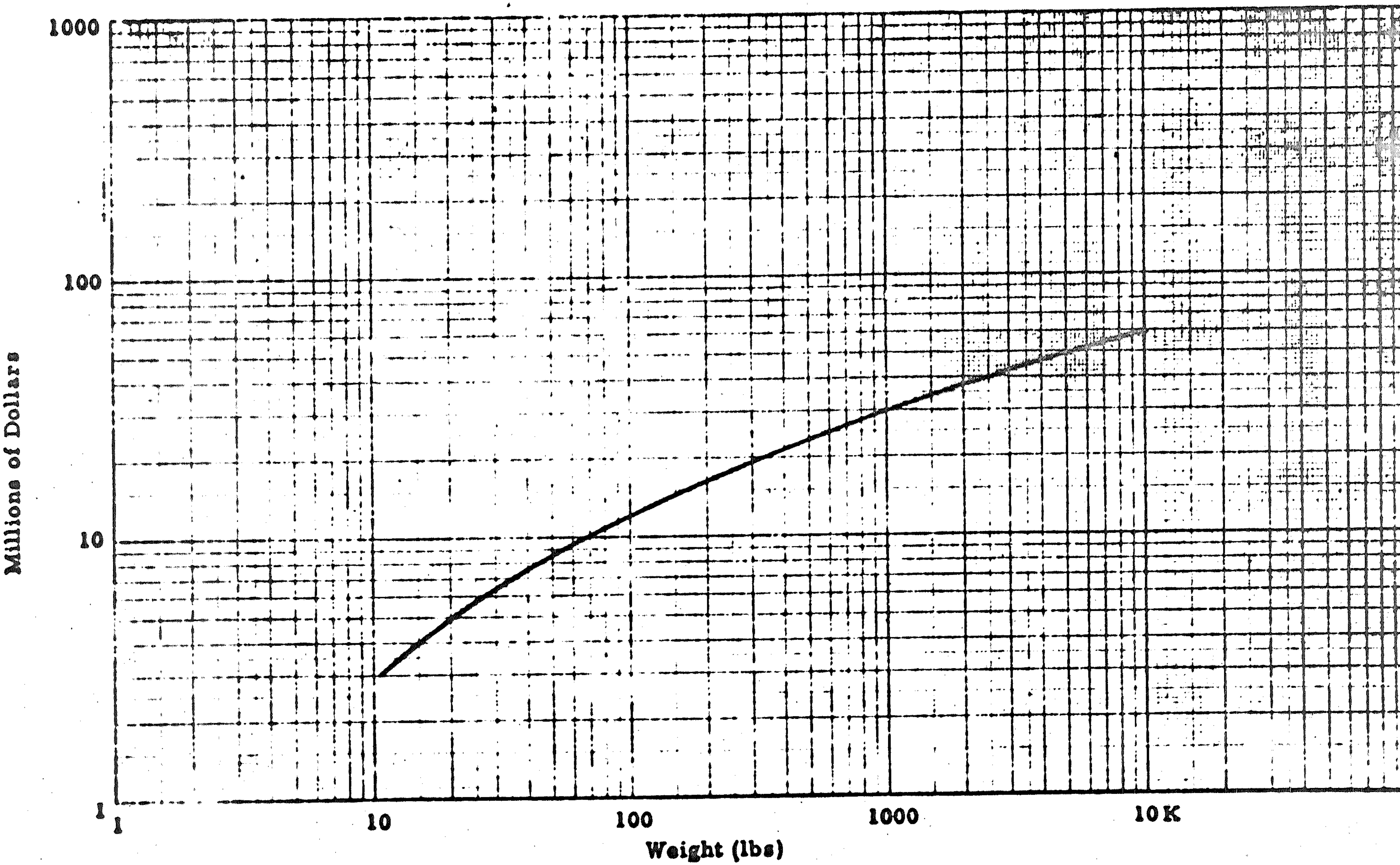


EXHIBIT 10A PAYLOAD (EXPERIMENTAL AND MISSION SENSORS) DESIGN/DEVELOPMENT COST

RE-ORDER No. 66-664

RE-ORDER No. 66-664

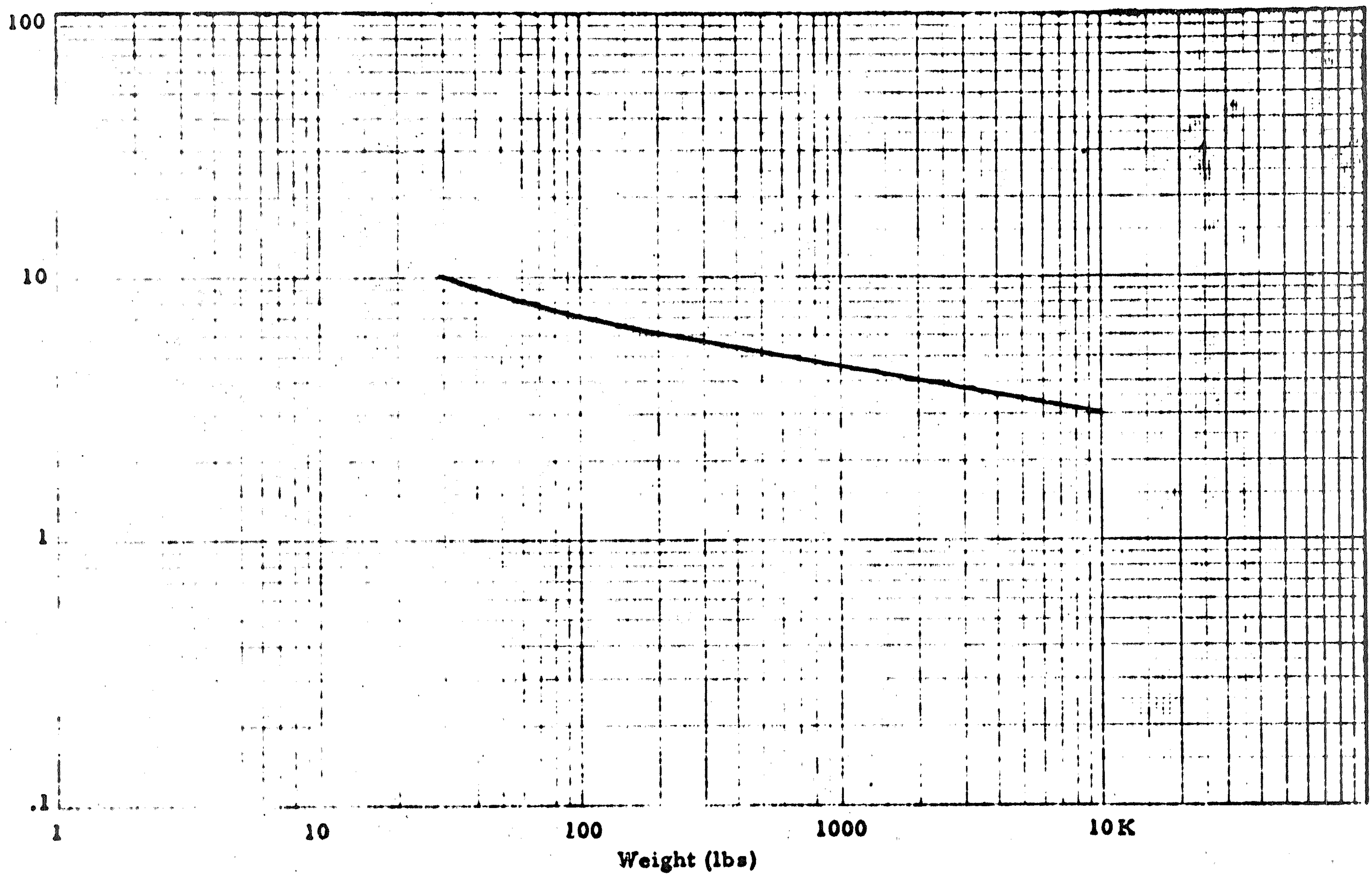


EXHIBIT 10B FIRST UNIT COST PAYLOAD (EXPERIMENTS AND MISSION SENSORS)

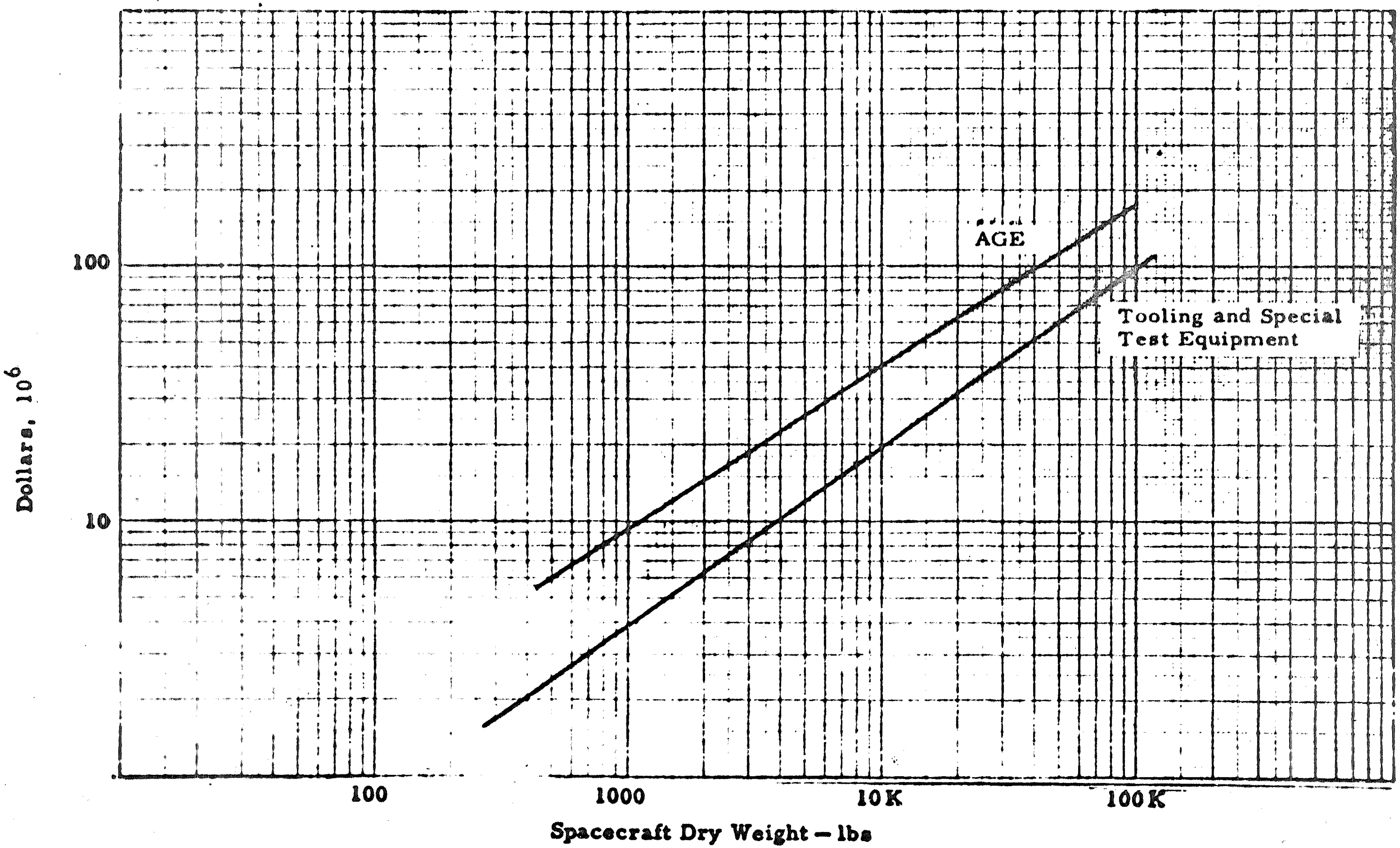


EXHIBIT 11A COST OF AGE, TOOLING AND SPECIAL TEST EQUIPMENT

RE-ORDER No. 66-664

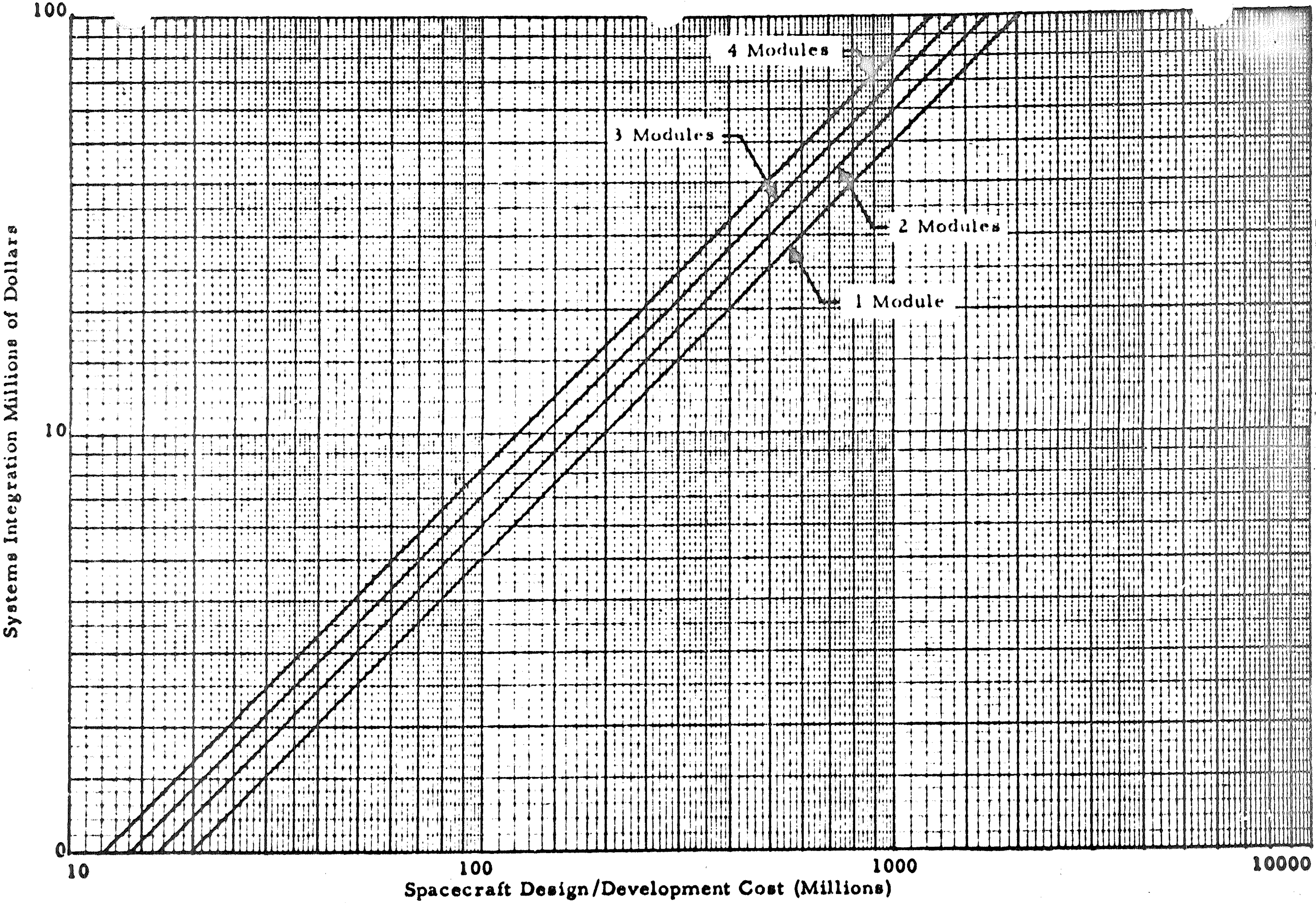


EXHIBIT 12A - COST OF SYSTEMS INTEGRATION

RE-ORDER No. 66-664

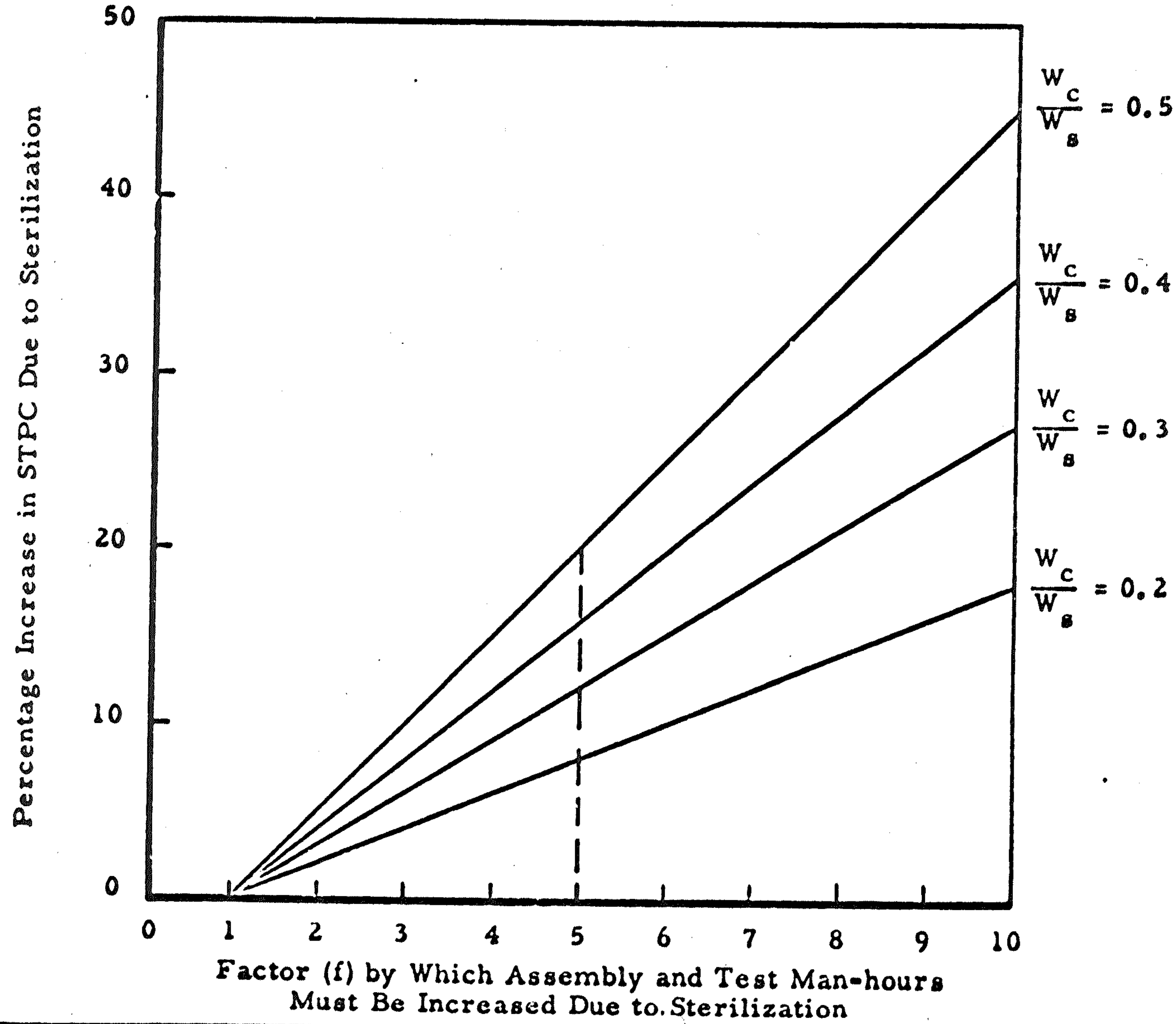


EXHIBIT 13 - INCREASE IN THE SPACECRAFT TPC DUE TO STERILIZATION

RE-ORDER No. 66-664

44

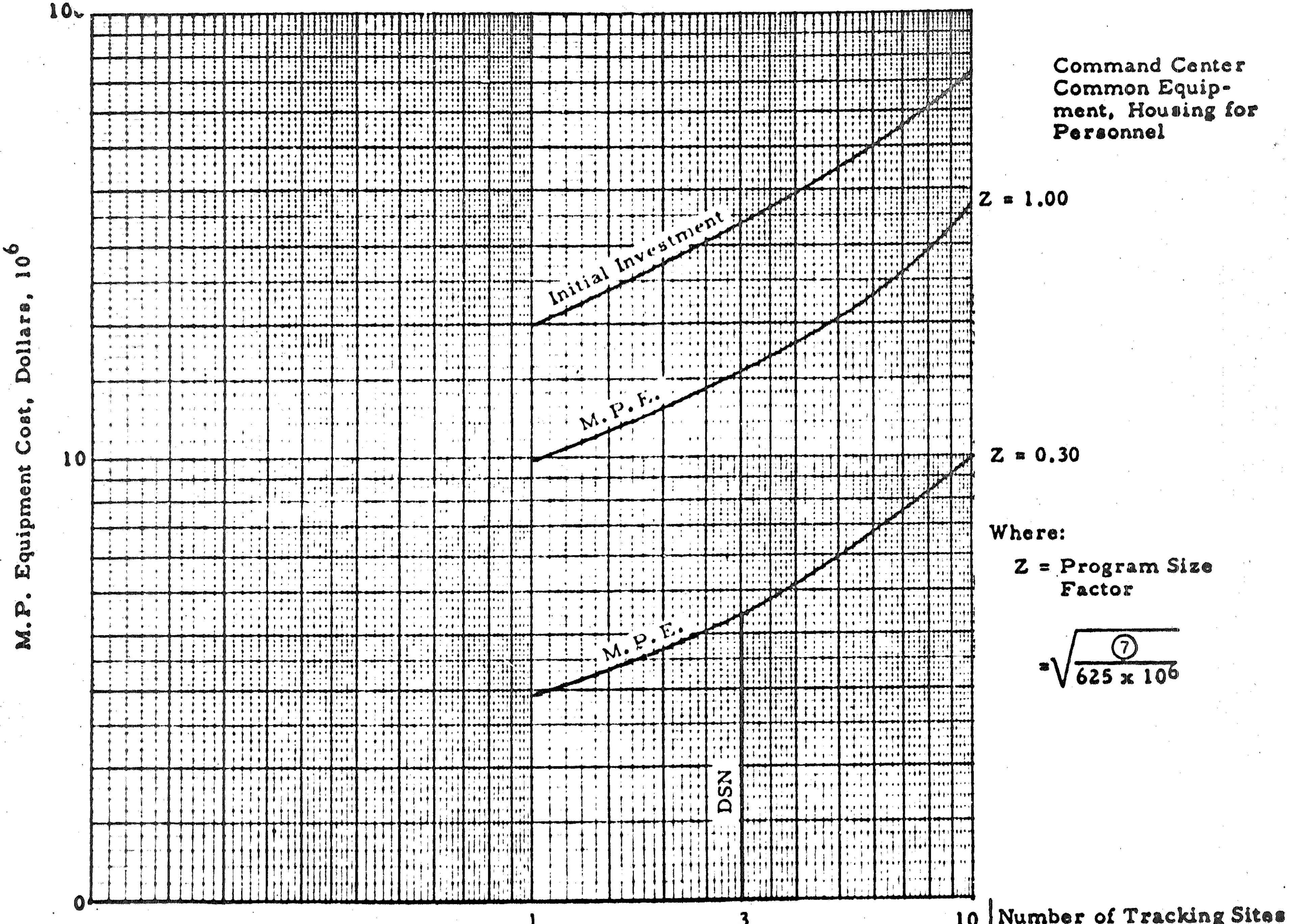


EXHIBIT 14 - MISSION PECULIAR EQUIPMENT (MPE) COST AT SFOF AND DSN

RE-ORDER No. 66-664

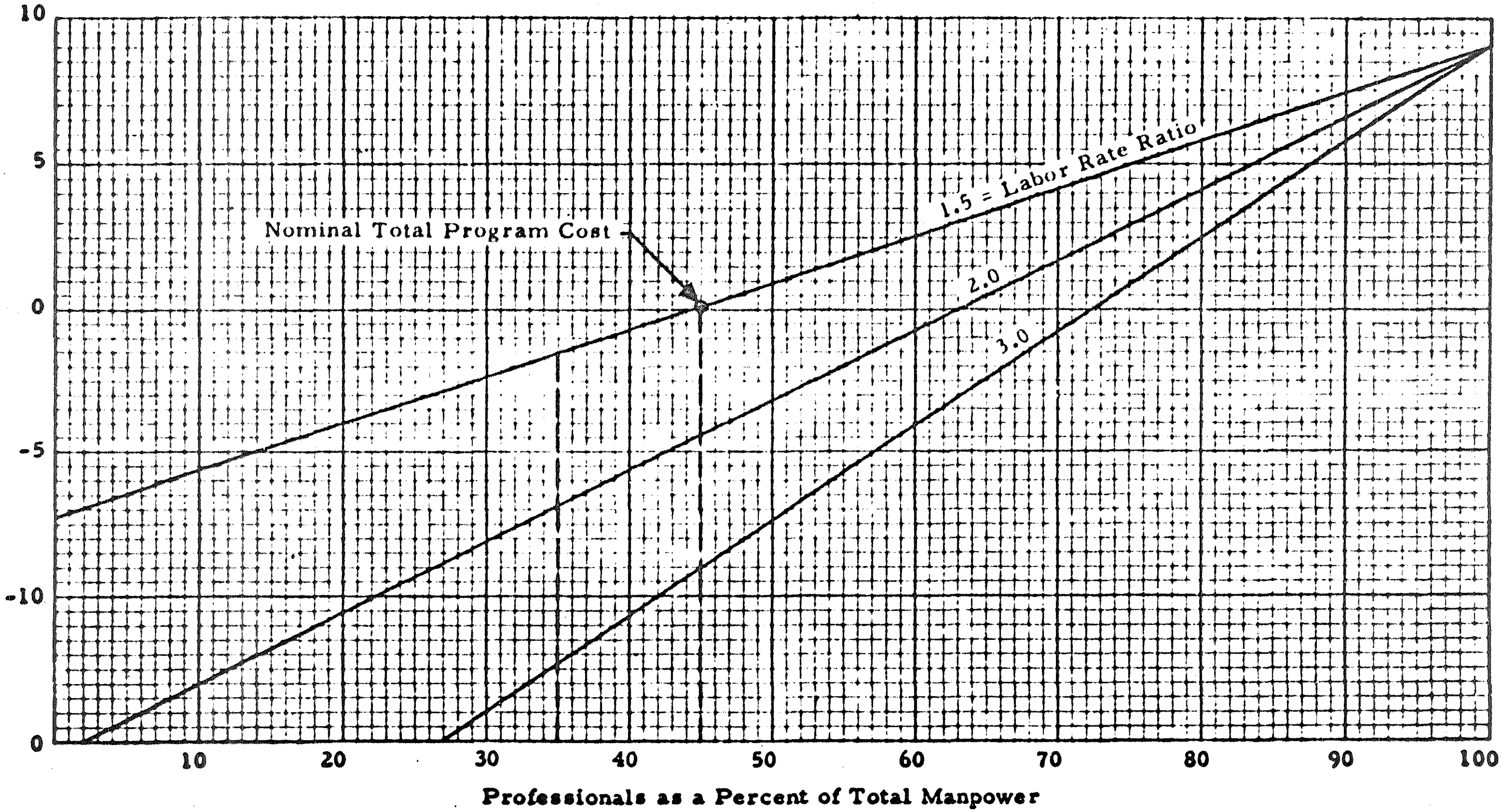


EXHIBIT 15 - MANAGEMENT IMPLEMENTATION MODE

RE-ORDER No. 66-664

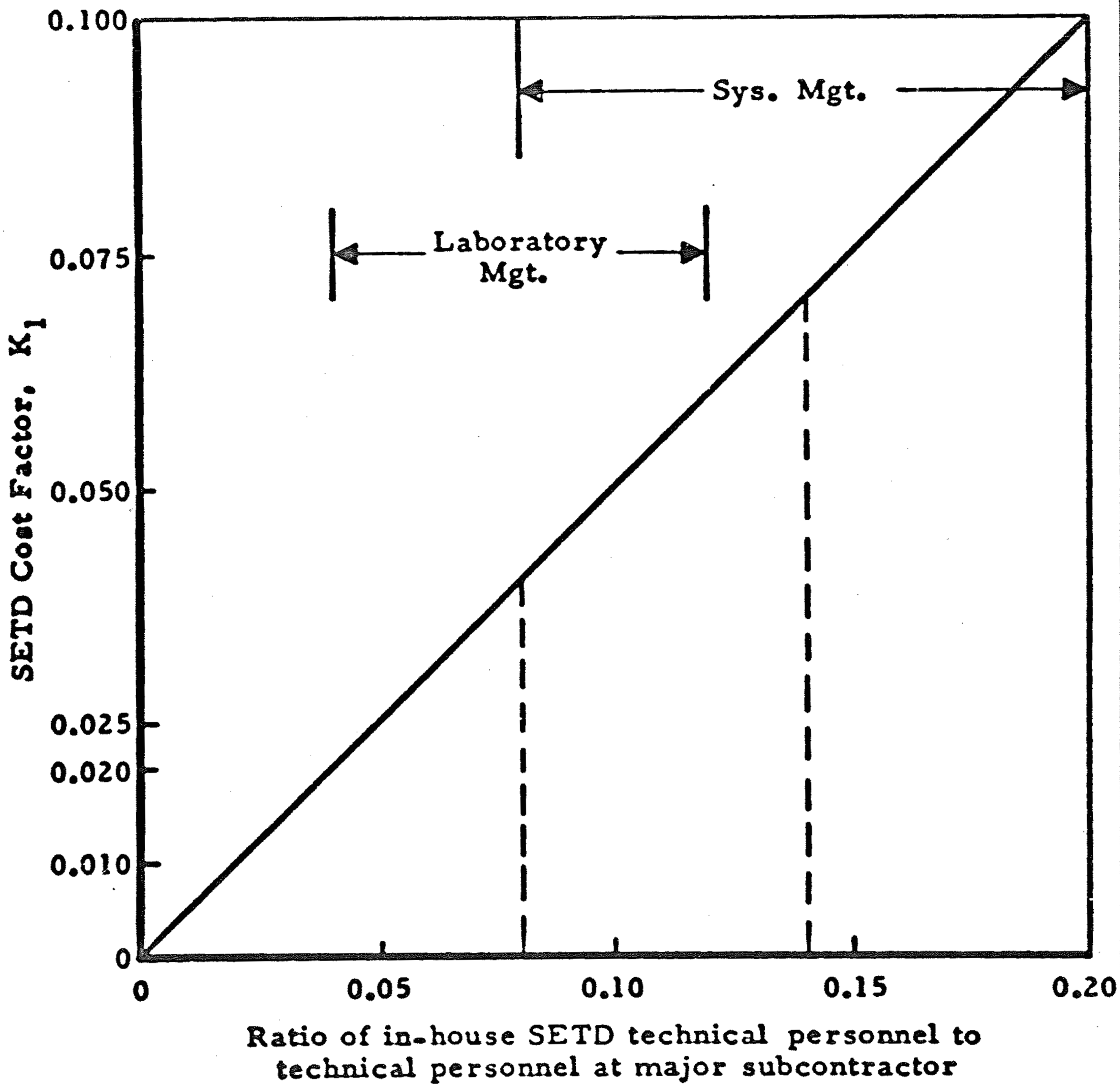


EXHIBIT 15A - SETD COST

EXHIBIT 16 - PROGRAM MANAGEMENT ALTERNATIVES

Schedule/Program Changes	% Increase in STPC
1. Nominal Program	0
2. Parallel Development (of alternate designs in high risks sub-systems from the start of Phase D)	22.0
3. Accelerated Development (crash development of three designs in each high risk sub-system from the quarter-point of Phase D)	37.5
4. Periodic Launch Rescheduled (to next launch opportunity at the mid-point of Phase D)	
A. no cut-back in level of effort	55.0
B. a two-thirds funding cut-back with gradual build-up reaching nominal spending levels one year prior to launch	24.0

RE-ORDER No 66-664

SPACECRAFT COST SUMMARY

ITEM	① DESIGN/DEVELOPMENT	② COST OF TEST ARTICLES	③ D/D PLUS TEST ARTICLES	④ INTEGRATION	⑤ COST OF FLIGHT ARTICLES	⑥ TOTAL COST
			① + ②	③ ∮ CER 12A		③ + ④ + ⑤
Spacecraft Module 1						
2						
3						
–						
–						
S/C Systems Integration - Increment Ref: ⑦ ∮ CER 12A		Σ ⑦			Σ	
					⑧	
				S/C TPC	⑨	

MISSION SUPPORT AND SPACE FLT OPNS	DESCRIPTION / INPUT	REF CER	OPERATION	COST
Program Management		–	0.05 ⑨	
SETD	Mgt Mode/Tech M/P Ratio	15A	K_1 ⑨	
Phase A	Adv Studies	–	0.01 ⑨	
Phase B	Conceptual Design	–	0.01 ⑨	
Phase C	Project Definition, System Design, ∮ Critical Hdw. Dev	–	0.05 ⑨	
Adv. Development	N_R = =Number of High Risk Sub-Systems	–	0.05 ⑨ $(1+\sqrt{N_R})$	
Sterilization	F = ; W_c/W_s = ; N =	13	/100 ⑨ x N/4	
M.P. Equipment	Mission Peculiar Equipment At SFOF ∮ DSN	14	Σ =	
M.O. Equipment	Mission Operations Training; T =	–	$0.60 \times 10^6 \times (T+3) + 0.2$(MPEC)	
Space Flt Opns	Mission Time (T) Months ; T =	–	$0.20 \times 10^6 (T+3)$	
Post Flt Analysis	Mission Time (T) Months ; T =	–	$0.40 \times 10^6 (T+3)$	
Mgt Impltn Mode	Mgt Implementation Mode:	15	K_2 ⑨	
Schedule / Program Chg		16	/100 ⑨	
Launch Vehicle				

1965 DOLLARS

RE-ORDER No. 66-664

SPACECRAFT COST

PROGRAM ____________

MODULE ____________

COST CATEGORIES	DESCRIPTION	QUANTIFYING PARMETER	PARAMETER INPUT	REF CER	DESIGN/ DEV'L'PT COST	REF CER	PARAMETER OUTPUT DOLLARS/—	FIRST UNIT COST	NO. TEST ARTICLES	COST OF TEST ARTICLES	NO. FLIGHT ARTICLES	COST OF FLIGHT ARTICLES	TOTAL HRDW COST
Structure		Weight (lbs)		1A		1B							
Propulsion Module Structure		Weight (lbs)		1.1A		1.1B							
Entry Structure		Weight (lbs)		1A		1B							
Propulsion	Liquid	Thrust (lbs)		2A		2B							
Retro-Propulsion	Solid	Weight (lbs)		3A		3B							
Navigation and Guidance		Weight (lbs)		4A		4B							
Stabilization and Control		Weight (lbs)		5A		5B							
Communications		Weight (lbs)		6A		6B							
Data Management		Weight (lbs)		7A		7B							
Electrical Power		Kilowatts		8A		8B							
Descent System		Entry Wt. (lbs)		9A		9B							
Experiments or Mission Sensors		Weight (lbs)		10A		10B							
AGE		S/C Dry Wt. (lbs)		11A		—							
Tooling and Sp. Test Equipment		S/C Dry Wt. (lbs)		11A		—							
TOTALS				▼Σ		1					2		
Systems Integration			1 + 2 =	12A									

RE-ORDER No 66-664

LAUNCH VEHICLE COST

STAGE ☐	QUANTIFYING PARAMETER	PARAMETER INPUT	REF. CER	FIRST UNIT COST (DOLLARS/LBS)	STRUCTURE (WT IN LBS)	FIRST UNIT COST (DOLLARS)	LEARNING CURVE	ITEM COSTED	REF CER	LEARNING FACTOR	COST OF ITEM (DOLLARS)	NUMBER ITEMS	COST (DOLLARS)
Structure	Stage Propellant Wt. (lbs)		Ex LV-1						Ex. LV-8				
Propulsion	Engine Thrust (lbs)		Ex LV-2	—	—				Ex. LV-8				
Guidance and Control	Weight (lbs)		Ex. LV-3		—				Ex LV-8				
Transportation Air ☐ Ship or Rail ☐	Stage Dry Weight (lbs)		Ex. LV-4	—	—	—	—	—	—	—	—	—	
Acceptance Test	Stage Gross Weight (lbs)		Ex. LV-5	—	—	—	—	—	—	—	—	—	
Launch Services	L.V. Gross Weight (lbs)		Ex. LV-6	—	—	—	—	—	—	—	—	—	
Propellants	Propellant Type		Ex. LV-7	—	—	—	—	—	—	—			

TOTAL ☐

Other Pertinent Data

Engine Type ☐

Engine Dry Weight (ea) (lbs) ☐

Stage Thrust (lbs) ☐